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INDEX.

Vol. X.

"The Aesthetic Aspect of Concrete Construction."
By C. F. A. Voysey.

"Dovetail Corrugate Sheeting."
By M. Noel Ridley, M.Inst.C.E.

"Industrial 'Safety First.'"
By Edward Willis, F.S.Q., A.M.Inst.C.E., M.Q.Mach.E., F.R.San.I.

Presidential Address.
By H. D. Searles-Wood, F.R.I.B.A., etc.

Syllabus of the Examination.

"Ferro-Concrete Ships."
By J. S. E. De Vesian, M.Q.Mech.E.

"The Design of Steel Structures."
By Albert S. Spencer.

"The Geology of Sands and Aggregates for Concrete Making."
By P. H. H. Boswell, D.Sc.

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THE CONCRETE INSTITUTE :

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Paper to be read at the Eighty-third Ordinary General Meeting of the Concrete Institute on Thursday, December 19th, 1918, at 5.30 p.m., at Denison House, 296, Vauxhall Bridge Road, Westminster, S.W.1 (close to Victoria Station), and CONFIDENTIAL *until after the Meeting.* *The paper is copyright, and is not for publication.*

The Aesthetic Aspect of Concrete Construction.

By C. F. A. VOYSEY.

" Tell me not in mournful numbers,
Houses are not what they seem,
For the walls that look so solid,
Once were poured from cans like cream."

The conservative instinct in some of us tends to strengthen our prejudices. And a fondness for hand work and the qualities of familiar building materials make one shy of the mystical concoctions that are more or less mingled with brains. Concrete seems one such that depends on conscience. The man that mixes the material must exercise his conscience, and who can measure the amount or tell its value? A brick seems more frankly to proclaim its qualities, and as with stone and timber, we know from past experience all that it can do for us. But concrete is an unknown quantity to many of us, except perhaps when

used in its simplest form, as for foundations. Another element of my prejudice is due to the recollection that greed is gratified by the use of concrete construction. That is to say, the shopkeeper who is out to make money wants to seize every inch of space. He thinks the display of his wares is better for him the more vast it is. Beauty has no charm for him and quantity is of more value than quality. The shopkeeper little realises how the mind and memory are debauched by vast crowds of articles jostling each other for attention. When a myriad of objects all shout at once, "Look at me!" we can carry away no lasting memory of anything but chaos. Concrete construction has helped in this direction. Meanness and greed I say are its parents. What can be expected from such an ancestry?

Besides the great difficulty experienced in making alterations to buildings so constructed, we find the greatly enhanced sound-conducting quality often very troublesome. And lastly, the imitative instinct in man has found abundant scope for its expression when making use of this form of construction. Buildings are made to look like stone or brick, and even at times like half-timber work. Deception gains eloquent expression in this material.

We usually find, when any new inventions first appear (like the railway train or the motor), they are made in the form of that which they are destined to replace. The evolution of things is quite evident to us all, so we may look forward with confidence to the time when concrete construction will have a character of its own and will cease to be made to look like anything that it is not.

We shall all agree, that the finest examples of building throughout the wide world have been the result of the consideration and understanding of the requirements and conditions obtaining at the time of their creation, and of the moral, intellectual and spiritual character of the people of their time and place. When these considerations have been neglected, and partial knowledge of foreign examples has fascinated us, then our architecture has become corrupted and exotic.

Therefore it follows, as the best work grows out of requirements and conditions, it is from requirements and conditions that the character of concrete construction must be evolved.

As the conditions for concrete are quite different from those for stone, brick or timber, the mode of its expression

must be different. Doors and windows are requirements, but the form they take must depend on conditions. Those conditions are chemical, substantial and functional. The ingredients of which concrete is made have their distinctive qualities, and any scientist could write a book full of facts concerning these things.

But beyond all this knowledge of conditions we have requirements equally innumerable and various. *What* do you want to build, is no more important a question than *why* do you want to build? After all the knowledge of material requirements and conditions has been gathered together and classified we shall find all this knowledge worse than useless, until we bring to bear upon it the moral, intellectual and spiritual sides of our nature.

Concrete, like our coat, may cover many useful appliances, but is useless without the soul within it. Someone said, "What is Mind—no matter; what is Matter—never mind." And yet I venture to say that there is mind of the utmost importance behind all matter, whether it be concrete or not. We cannot help conveying a spiritual something to everything we create.

The unseen is the glory of the seen. The cathedral speaks to us, and the heavens declare the glory of God. Man is born to be a creator; and as Nature is bursting with songs of praise, audible to all who will listen, so man must make his works shout with joy, and stimulate our higher nature through ministering to the spirit.

It is no use to tell me engineering is not an art. For I tell you Art is only the manifestation of thought and feeling, and it is not only possible but essential to us all. We cannot live a day without it, though many know it not. There is in everything a spiritual something, that appeals to every human heart that will listen and look. So with your concrete or your marble, the heart of man may be made to rejoice.

Bad workmen find fault with their tools, and as concrete is in a sense one of our tools, we must not quarrel with it; though doubtless some will quarrel with my simile and say a tool is the instrument by which something is created, whereas concrete is the creation itself. Now this is a great fallacy. Concrete in itself is an ugly thing. But concrete construction considered as a servant and as means to an end can be made a ministering angel. It is a good servant, but a bad master. A good servant, only so long

as it is kept in its place. There are many kinds of buildings which, it could be argued, would be more suitably constructed in concrete than in any other material. But there are other kinds for which concrete would be most unsuited. It is therefore necessary to admit the unique character of concrete in order to use it fittingly and artistically.

The choice of our material, when designing a building, is like the choice of words and phrases when we are writing or speaking. It is never an affair of the pocket only. The £.s.d. argument must not be permitted to spread its poisoned gases over all æsthetic considerations, that is, if the world is to be made better.

We shall surely all agree that proportion is of vital importance to the subject in hand. The sense of relation is only another aspect of the sense of proportion. It enters into all the affairs of life and into all our calculations of fitness. It is the manifestation of personal character. Every man's sense of proportion varies as his character varies, and is unlike all other people's sense of proportion quite as much as his character is unlike and is the very essence of personality. This lovely provision of diversity is a godsend. It makes everyone feel that in matters of beauty there is no finality, and that everyone is entitled to hold his own views as to what is or is not beautiful and praiseworthy. The proportion of the aldermanic watch-chain to the background of waistcoat is one of the little tell-tales we all have noticed. And in contemplation of the details in human existence, from the smallest to the greatest, we find the sense of proportion constantly being appealed to. No less then is it a fundamental quality in all our buildings.

It is my firm conviction that the beauty of concrete construction must mainly consist in right proportion. What are right proportions? Each must ask and answer for himself. I refuse to have any formula forced upon me, either Greek, Roman or Gothic. It is a matter of feeling and is capable of refinement, for ever evolving and developing as we advance in spiritual, moral and intellectual culture. We want no dogmatic statements of what is in good proportion any more than we need a definition of truth or beauty. All are growths, for ever being purified and lifted higher.

It is quite true that the Greeks arrived at what we regard as perfect proportion, but it was perfection as applied to given objects. Definite groups of requirements and con-

ditions were beautifully proportioned, but to copy these proportions in designing the portico of a public-house is like grasping at the shadow and forgetting the substance. It is like using Latin quotations to an audience of peasants; it serves well to glorify the speaker and suggest his superiority. But oh! what a contemptible vanity it is! Of course, our educational experts will say that it is surely better that the indifferent public-house architect should copy the Greek than that he should inflict upon us his own Philistine ideas of proportion. I hear the crowd say "Why, certainly." But think a minute, and I trow you will recall Shakespeare when he says, "This above all, to thine own self be true." Give me the true man or the true villain. There is infinite possibility for the sincere; but the imitator, the plagiarist, the monkey, and the parrot are fit only for the Zoological Gardens.

Those who are steeped in archæology cannot glorify concrete construction. Precedent and ancient fashions will not help us here. Man is born to develope his character, and new modes must be evolved for new materials. We have all the faculties for the purpose, if we will only exercise them.

Descartes said, "The more we concentrate attention on the past, the less we shall understand and appreciate the present." So to make the best use of concrete construction we must divorce ourselves from the past modes of architectural expression and try to enter into the spirit of our new material, and to dominate it with that which is highest and eternal in our nature.

Men with delicate feeling will express beauty through any medium; and provided they are not hide-bound by tradition, they will create that which breeds beauty of character. In this life there is no higher calling.

There is one thing for which we must be thankful to concrete construction, namely, that it has forced upon us the necessity for a revision of the building by-laws. These foolish and mischievous irritations must be revised, if not repealed altogether, for the stupidity of veneering concrete construction so as to give it the appearance of stone is fraudulent as well as foolish. Veneer, when frankly applied, is legitimate enough, but it is open to question as to whether a concrete building cannot be made beautiful and satisfying without veneering it all over. The texture of concrete might be made as pleasant as stucco. It is quite doubtful whether

we should allow the expenditure on veneer, the purpose of which is purely and only to enhance appearances. True architectural beauty, to my mind, must be wedded to structural function. Therefore the form of your concrete and mode of its use must embody elements of beauty, and not depend for its charm entirely on superimposed material of quite another nature. This suggestion can only be applied in certain cases, and is not a principle of general application. It should not be used as an argument against mural painting or mosaic. It would surely be quite possible to put up a concrete building in good proportions with the concrete walls exposed to view in naked frankness and wedded to certain features of stone or native marble. The main entrance of such a building, having an heraldically carved surface above, richly coloured and gilded, would surely be a quite legitimate treatment.

The most difficult branch of this subject would seem to be suggested by the question, How far may we, for the sake of calling up association of ideas, use the arch form?

We cannot deny that the Gothic arch has a profound effect on our minds and hearts, and is structurally the practical outcome of small stones and bricks. The lintel would seem, structurally speaking, the most suitable form for concrete construction. The four-centred arch of Tudor times can be easily made in concrete, but it is surely much more complex than the lintel. The slightly-pointed arch is so dear to me that I want to modify and limit all my principles to admit it. Like all weaklings, I wish to be sound and logical, but pure feeling, which enemies sneer at and call sentiment, gets possession of me and carries me off into the clouds. We love to appear intellectually great and scientifically sound, but not at the expense of all human emotion. This little touch of inconsistency, this human frailty that abandons itself to pure emotion, is one of the most human of all human charms, and thus it comes about that it is the unseen that is the glory of the seen. The emotion is buried beneath matter, not to rot, but to regenerate.

The rank materialist, the atheist, and the scientist are, thank God, one and all human, fallible and loving. Otherwise we should want to crucify them. These same qualities are what make life so interesting and stimulating. Therefore I say you *must* mix them in your concrete construction if you have a spark of love or regard for your fellow-

creatures. The desire to give rather than to get, which is the mainspring of all creative energy that is beautiful, must make us study fitness in order to serve well. And by this careful study of requirements and conditions, and by fidelity to all that we think beautiful and true in human thought and feeling, we shall, I think, be able to evolve a mode of concrete construction as unique and personal to the material as any stone-constructed building that was ever created. And for this purpose the less we are familiar with foreign or ancient styles the better.

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Dovetail Corrugated Sheeting.

By M. NOEL RIDLEY, M.Inst.C.E.

Dovetail corrugated steel sheeting consists of flat steel sheets, crimped into the form of dovetails, and is usually crimped in three depths, viz., No. 1 of $\frac{3}{4}$in. section, No. 2 of $\frac{1}{2}$in. and No. 3 of $\frac{1}{4}$in. section. The maximum size of sheets is 3ft. 9ins. wide, that is, in the direction of the corrugations, and 5ft. 6ins. in length, or across the corrugations. The sheets vary in gauge from 20 to 28. It is only section No. 1 ($\frac{3}{4}$in. in depth) that can be crimped to 20 gauge.

These sheets were put on the market about 24 years ago, and are used generally for fireproof partitions 2in. to 3in. thick, fire enclosures to stairs, fireproof lift enclosures, Mansard and other roofs, strong rooms, linings against damp, theatre balcony fronts, proscenium fronts, and for fireproof floors, beams, columns, and even for complete buildings.

It is more usually used in conjunction with plaster, sand and cement, or concrete, and forms in combination, and in reinforced concrete construction, because the steel and the concrete work together in harmony in the same way as reinforced concrete made with concrete and steel bars.

The author's definition of reinforced concrete is as follows :—" Concrete reinforced with steel or other reinforcement so that the steel and the concrete will work in harmony, the concrete taking the compression, and the steel the tensile stresses, or the steel may be in compression working in harmony with and reinforcing the concrete.

Further, it is to be noted that for the purpose of this

definition any material may be termed concrete, that sets from a plastic state and hardens so as to work in harmony with the steel in taking up the stresses.

The following test shows that dovetail corrugated steel sheeting fulfils this condition.

ntrated
al Load
n. by 2ft.

The construction of test slab is as follows:—One 2ft. length of 2ft. 6in. shallow or No. 2 sheeting with 3in. bearing, ends free; 1½ins. of concrete on top, made of coke breeze and cement, mixed five to one on top; ½in. sand and cement and four to one underneath; clear span 2ft.; concrete 40 days old.

The total load at collapse of slab was 3,696lbs., which is equivalent to 1,848lbs. per sq. ft. At this load the dovetail sheeting had not broken.

The author has calculated the strain on the coke breeze as 1,492lbs. per sq. in., and of the wrought iron sheeting as 21.62 tons per sq. in. The ½in. sand and cement on the under side of the sheeting does not figure in the calculation, and the effective depth is taken as 2in. This result could not have been obtained if the sheeting had not been working in harmony with the concrete.

rties of
ail Corru
Sheets.

Each dovetail corrugated sheet in length or across the corrugations requires 1ft. 9ins. of flat sheet, so that a sheet weighs one and three quarter times a flat sheet. Theoretically if the corrugations are made in proportion for any variation of depth the ratio of crimped sheet to flat sheet will always be the same, but in practice the ½in. sheets are usually made 1½ to 1⅝ that of flat sheets, and the No. 3 section about 1⅓. This proportion can be still further varied if required, also a section with greater intervals between the dovetails can be used.

For purposes of comparison the following table gives the properties of dovetail corrugated sheets, ordinary corrugated sheets and flat sheets.

Description.	Depth of Sheet.	Gauge.	Section Modulus.	Safe Strength of Sheet at 1ft. span.		Weight per sq. ft. lbs.
Dovetail Sheet ...	¾in.	22	0.1647	108 lbs.	per sq. ft.	2.223
	¾in.	26	0.1062	70	do.	1.4
	¾in.	22	0.1098	73	do.	2.223
	½in.	26	0.0709	47	do.	1.4
Corrugated Sheet	⅝in.	16	0.1718	114	do.	2.958
	⅝in.	22	0.0859	57	do.	1.467
Flat Plate ...	$\frac{3}{32}$in.	3	0.1582	105	do.	11.47

NOTE.—The unit stress is taken as 16,000 lbs. per sq. inch.

The full theoretical strength of dovetail corrugated sheets can only be obtained by filling in the corrugations with concrete or stiffening the corrugations in some other way. The ordinary corrugated sheets do not require such stiffening.

The ratio of weight of ordinary corrugated sheet is 1.16 of the flat sheet compared with 1.75 of dovetail corrugated sheet.

From the above it will be seen that dovetail corrugated sheets are 50 per cent. heavier and 100 per cent. stronger than ordinary corrugated sheets for same depth and gauge. For sheets of the same strength ordinary corrugated sheets are one-third heavier than dovetail corrugated sheets. A flat steel plate $\frac{9}{8\,3}$in. thick and weighing 11.47lbs. per sq. ft. is of equal strength to $\frac{3}{4}$in. 22 gauge dovetail corrugated sheet and $5\frac{1}{8}$ times as heavy.

Uses of the Sheets.

The No. 3 dovetail sheeting is used extensively as a damp-course in conjunction with sand and cement. It is a perfect preventative of the damp rising in the walls, and what is more important, makes a material of greater hardness than the bricks, and in fact forms an integral part of the wall, there being no chance of squeezing out. It is used also for linings to walls, nailing to wood studs for timber partitions, etc., for laths in place of timber laths for ceilings, forming panellings to ceilings and walls, and backings to cornices and various decorations and enrichments, the plaster being easily worked to the required shape on the dovetail sheeting, which is readily adapted to any form or shape required. It is also used to cover rolled joists, stanchions, etc., as a backing for plaster work.

No. 2 section of shallow sheeting is used for permanent centering for slabs, floors, beams, roofs, columns and partitions, also outside wall cylinders, etc.

No. 1 section is also used for partitions and walls with or without H and channel irons for railway carriage floors, for stiffer permanent centering, etc.

Partitions.

The sheeting was used for partitions over 23 years ago, the thickness being 2in. to 3in. At that time it was the surprise of the building world owing to its great strength and fireproof and sound-proof qualities. In fact, for this purpose it seems to hold a premier position to-day, where these qualities are required. These partitions are constructed as follows :—Small H iron bars are fixed vertically from 2ft. to 3ft. apart, and the spaces between them are filled in with

the dovetail sheets, usually of No. 1 section; the dovetails are placed horizontally. This skeleton partition, of great

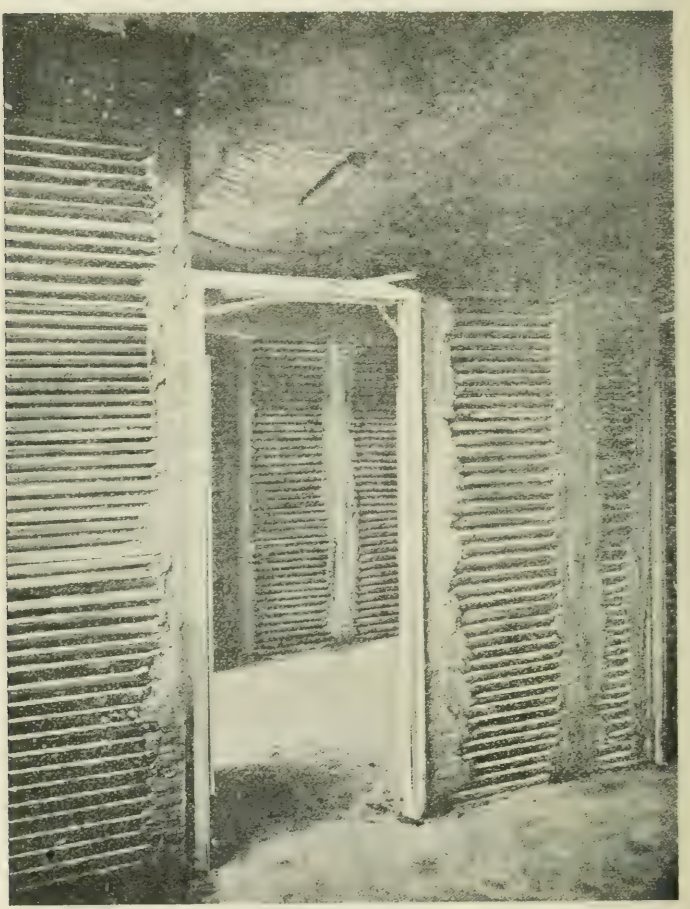

FIG. 1.

stiffness, is then plastered to the required thickness on both sides. The dovetails form an excellent key to the plaster, the concrete and steel being thus homogeneous; and for

the reason stated above this forms a reinforced concrete partition. It is also fire, sound, damp, and vermin-proof, which is a very great consideration. Fig. 1 is a photo showing cubicle partitions, etc., as erected and ready for plaster. Fig. 2 is a photo showing the roof and top of the upper portion of the partitions to cells of the Old Bailey Temporary Prison erected for the Corporation of the City of London; the uprights are shown "screeded."

This temporary prison was erected throughout with this material, the wall of the cells being about 3in. thick, and this type of construction has been used for the floors and cells of several of H.M. prisons.

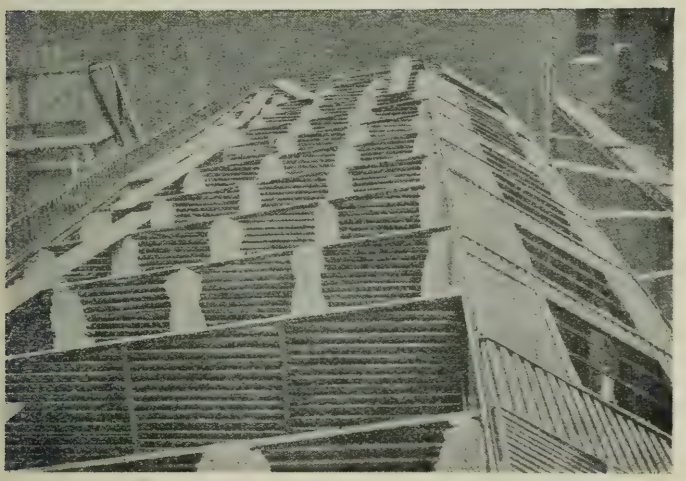

FIG. 2.

Several large partitions have been erected, about 24ft. by 24ft., and plastered with sand and cement in the offices of H.M. Government, and it is impossible to tell (if there is no doorway) the difference between the thin partition and an 18in. brick wall. The dome and barrel ceilings of the National Gallery are other illustrations of this method of construction. The old lath-and-plaster timber work of the magnificent domed and barrelled ceilings was removed and No. 2 dovetail corrugated steel sheeting replaced the timber work. The curved panelling and heavy mouldings were

plastered on to it, so that it became a replica of the old panelling.

Another type of partition and walls omits the H irons; usually No. 2 or shallow sheeting is used. The sheets are joined together by lapping, to make them the required length and are placed in position with the dovetails horizontal, and a few ¼in. round bars are placed vertically on both sides of the sheeting, which is then plastered. This partition is of equal strength to the partition before mentioned, but has less stiffness previous to plastering.

At the commencement of the war the Admiralty required the erection of large buildings in the Falkland Islands for wireless telegraphy. The weather conditions there are very bad; the cold is intense, and terrible storms frequently occur. To meet these conditions it was decided to use dovetail corrugated sheeting for the outside and inside walls and also for the roofs. These were plastered in sand and cement. The outside walls were rendered to a thickness of 4in.

This system has been largely used for tanks, retaining walls, tunnels and other linings, and for curved gallery fronts. It has special advantages for curved surfaces and arched work.

w Walls

For outside walls, hollow walls have been a success. Two walls of skeleton sheeting are erected in either of the aforementioned methods with a space of 2ins. between them and they are tied together at intervals. The outer sides only are plastered to the required thickness. The usual total thickness of these walls is 5½ins. This type has been used in important Government buildings.

Slabs

Floor slabs are usually constructed with No. 2 section sheets, and are lapped in the direction of the corrugations to the required span. The sheets are placed in position and supported at intervals, but without shuttering. Round bars of small section are bent to the required shape, as is usual in reinforced concrete work, and are placed in position. The floor slab is then concreted to the required thickness. For purposes of calculating the strength of the floor slab, the sheeting is taken as the equivalent of reinforcement of .25 sq. ins.

s.

For beams the sheeting is made in the form of a trough, the depth of the trough being the depth of the beam below the slab. Flat iron stirrups are placed round the trough and are bolted to it. The top of the stirrup on both sides of

the trough is carried up above the trough to within $\frac{1}{2}$in. of the intended surface of the floor, and at that point the stirrup is bent across the trough and the two ends are bolted together ; it is impossible for the stirrups to slip. To form the reinforcement, bent round bars are used and placed in the trough or skeleton beam in the usual manner. The skeleton beam is erected and supported and is stiffened at intervals without shuttering, and when the reinforcement bars are in position, the beam is concreted.

FIG. 3.

Columns.

For columns the sheeting is formed in the shape of a cylinder or tube with the dovetail sheeting corrugations in the direction of the length of the column. The stirrups are of flat iron, placed at the required distance apart round the cylinder or tube and are bolted to the sheeting.

The skeleton columns thus made have great stiffness. They are placed in position and only require strutting up to prevent movement ; they are then concreted from the top. If it is required to have additional longitudinal reinforcement, straight round bars are customarily used and are placed ready for concreting in their positions in the skeleton column. These columns have great simplicity in erection. In all cases after completion the exposed dovetail corrugated sheeting is rendered.

gth of tion and s.

A partition was tested 10ft. long by 10ft. high, loaded up to 10 tons, without a sign of fracture or movement as shewn in the illustration (Fig. 3).

Flat reinforced concrete roofs have often been placed on the top of these partitions. The walls and partitions can always be relied upon to take considerable weight.

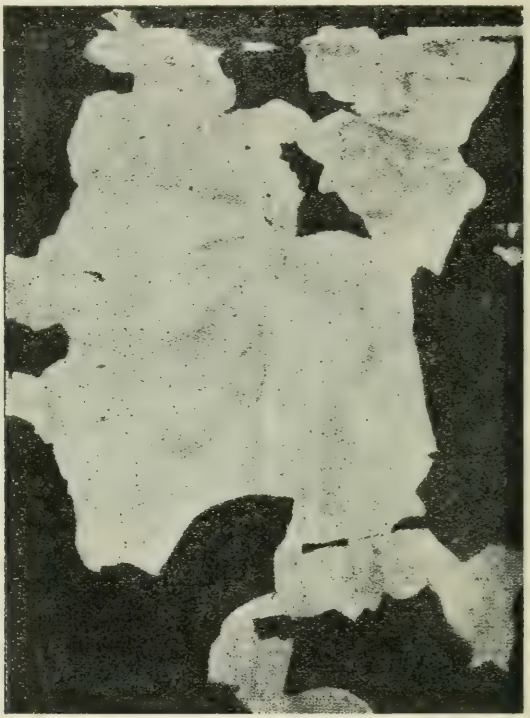

FIG. 4.

d-proof ties.

The peculiar form of corrugation is very helpful in minimising and breaking up the spread of sound; its impenetrability is unique. For thin partitions (2ins. and 3ins. thick) this point is of importance, and this applies to reinforced concrete roofs and floors constructed on this system and also to wood floors with dovetail sheets to form a ceiling.

Fireproof qualities.

There have been many cases where the fireproof qualities of these partitions have prevented a fire from spreading with disastrous results. In 1904 a fire occurred at 198, Oxford

FIG. 5.

Street, London. The fire was confined within the actual area of the partition which prevented the spread of the flames, thus saving the building from what would have been

FIG. 6.

undoubtedly a disastrous fire. The architect stated that "The fireproof qualities of the dovetail corrugated partitions are exemplified in the fire which occurred recently at these

buildings. Notwithstanding the great heat and the extreme test to which they were subjected, the partitions have remained intact, and thus kept the emergency exit, required by the L.C.C., uninjured, and no doubt the partition very materially helped to save the rest of the building." Fig. 4 is a photograph shewing the effect of fire on one of these partitions. It will be noticed that the setting coat has flaked off in places, probably due to the water played upon it by the firemen.

Domes are usually constructed in the following manner: Small H irons are bent to the curve of the dome in vertical section, fixed radiating and connected at the top to a circular plate or channel iron ring of suitable radius. Dovetail corrugated sheeting is fixed between the H irons with the dovetails horizontal, and when necessary, round bars, resting on the H irons, encircle the dome. The outside is then concreted to the required thickness and the dome is rendered on the inside. No centering is required, but only strutting up and the necessary stiffening while work is going on. Thus all the expensive curved centering is obviated. The domes of the Walton Library, Liverpool, and the Congregational Church, Fairhaven, were constructed in this way. Each of these domes is over 40ft. in span. A large number of other domes have been erected on this system.

The advantages of the dovetail corrugated sheets for roofing are many. The roof is easily erected; a minimum of concrete (from ½in.) can be placed on top of the sheets, making a 1in. slab, if the under side is not rendered or only the dovetails are filled up; if rendered it will amount to not more than 1¼ins. thick. Usually no strutting is required.

Large ventilating air trunks have been constructed with H irons and dovetail corrugated sheets. The H irons are bent to the shape of the trunk, which is completed by rendering on both sides.

A photograph (Fig. 5) is shewn of a mansion at Hardelot, near Boulogne. The archwork and columns seen in the photograph are on this system of reinforced concrete.

Fig. 6 shews a Racquet court pavilion with the outside walls constructed on this system.

Fig. 7 shews the gallery at the Drill Hall, Maidstone. The whole of the gallery, including the cantilever beams and the gallery front, are constructed on this system.

Fig. 8 is an illustration of the Royal Wimbledon Golf

FIG. 7.—The Drill Hall, Maidstone.

FIG. 8.—The Royal Wimbledon Golf Club House.

Club House, in course of construction. The outside and inside walls, floors, columns, and staircases were constructed on this system.

Figs. 9 to 11 illustrate the reinforced concrete construction on this system in the Women's Settlement at Canning Town.

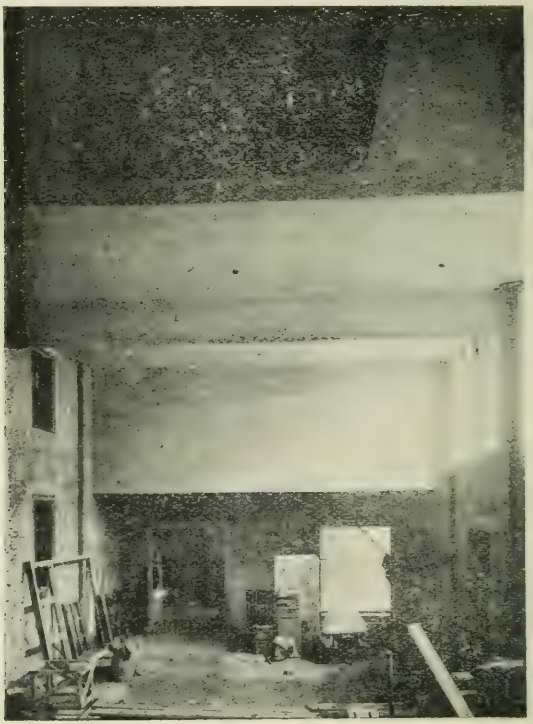

FIG. 10.—Women's Settlement, Canning Town.

Fig. 12 shews partitions, etc., in course of erection at the Maida Vale Insurance Building.

Figs. 13 to 17 show photographs of Deller's Café, Exeter, during construction. Most of the beams and columns are of reinforced concrete, as also are the floors and staircases. The beams shewn in Fig. 16 are 40ft. span.

FIG. 9.—Women's Settlement, Canning Town.

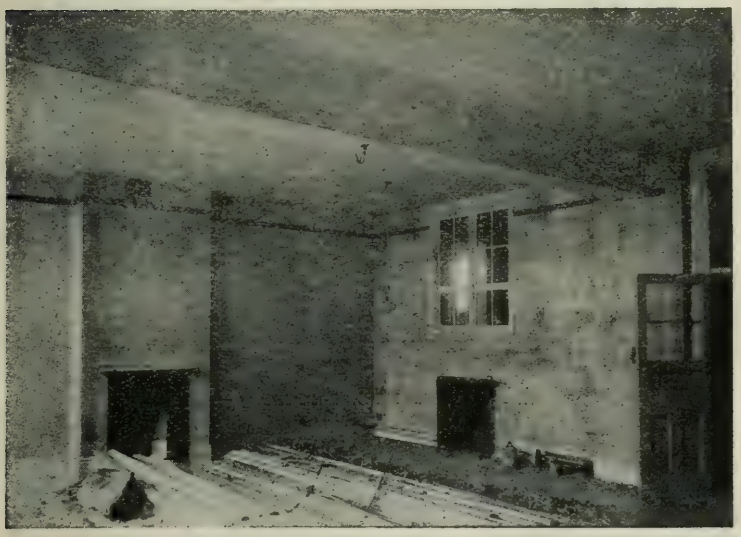

FIG. 11.—Women's Settlement, Canning Town.

In this building a departure from the accepted method of bending moments has been made. For continuous work the

FIG. 12.—Maida Vale Insurance Building.

theory adopted has been to proportion the stress according to the moment of resistance. For instance, for two-span con-

FIG. 13.—Deller's Café, Exeter.

tinuous beams or slabs with distributed loading the moment adopted is $\frac{WL}{11.656}$ for stresses at haunch and centre of spans, making the point of contraflexure of the cantilever portion 0.1716, and of the supported portion 0.2824 of the span. For fully continuous spans $\frac{WL}{16}$ for stresses at haunch and centre, in both cases the moment of resistance being the same at

FIG. 14.—Deller's Café, Exeter.

haunch and centre. The point of contraflexure for the fully continuous spans of the cantilever portion is taken as 0.14645 and of the supported portions .7071 of the span.

The point of contraflexure was therefore varied according to the moment of resistance provided, and the limitations caused by the usual theory removed. The floors and beams thus designed were of great stiffness and just as satisfactory

as others which the author has designed on the usually accepted moments. This method of designing has the advantage of giving greater latitude and often gives an economy of material. For the correctness of this theory there is considerable evidence (some of it by tests) that tends to show that it is a more reasonable theory than the existing one (even if it is not absolutely correct), and further, that the using of it is of no detriment to the work.

FIG. 15.—Deller's Café, Exeter.

In a book written by Fred. W. Taylor, M.E., Sc.D., and Sanford E. Thompson, S.B., M.Am.Soc.C.E., entitled "A Treatise on Concrete Plain and Reinforced," they describe some interesting tests on beams supported at the ends and on two and three-span continuous beams. The supported span tests are only directly comparable with the continuous span tests by the stress per sq. in. at the time of failure.

The continuous T-beams were in section 1ft. 11½ins.

width over all by 1ft. $7\frac{3}{4}$ins. depth over all, the thickness of T-slab $3\frac{1}{8}$ins., and the thickness of beam $9\frac{7}{8}$ins. The reinforcement consisted of five bars $\frac{11}{16}$in. both at haunch and centre. The three-span beam had the same reinforcement at haunch and centre with the addition of three $\frac{11}{16}$in. bars in the slab or table of the centre span. These continuous beams were calculated on the accepted formula ; but it is difficult to understand why equal area bars should be placed

Fig. 16.—Deller's Café, Exeter.

at haunch and centre under this formula. The result of these tests is extraordinary, and is as follows :—Failure took place for the supported span at 9,765lbs. per lineal foot on the assumption of supported slab tests. For the two-span continuous, 14,242lbs. per lineal foot, and for the three-span, 12,600lbs. per lineal foot. The three-span continuous beam was only loaded on the two end spans, the centre span being unloaded and an upward deflection formed, thus utilising the $\frac{11}{16}$in. bars in the top flange of the centre span and neutralising

two bars of the five $\frac{1}{16}$ in. bars of the haunch. If the calculation of the continuous beams is made on the moment of $\frac{WL}{11.656}$ for the two-span continuous beam with five bars $\frac{1}{16}$in at haunch and the three-span continuous beam with three effective bars $\frac{1}{16}$in. at haunch, and the supported span $\frac{WL}{8}$, then in all three types of test beams the stress per sq.

Fig. 17.—Deller's Café, Exeter.

in., at failure, of the steel bars is about the same, and in accordance with the above new formula. This clearly shews that continuous spans with equal resistances are stronger than the accepted formulæ shew. To quote from the above-mentioned book, page 442, "Type 2, the beams continuous over two spans failed at the support at an average load 14,240lbs. per lineal foot, the theoretical bending moment at the support is $\frac{WL}{8}$ the stress in steel at

the support at the maximum load figured at the basis of the above bending moment is about 64,000lbs. per sq. in. It is evident that this stress is much higher than the elastic limit to the steel used in the test which shews that assumed theoretical bending moment coefficient is too large. Based on the moment of resistance for yield point of steel we get a bending moment coefficient of 10 instead of 8."

In the accepted formula of $\frac{WL}{8}$ for two-span continuous

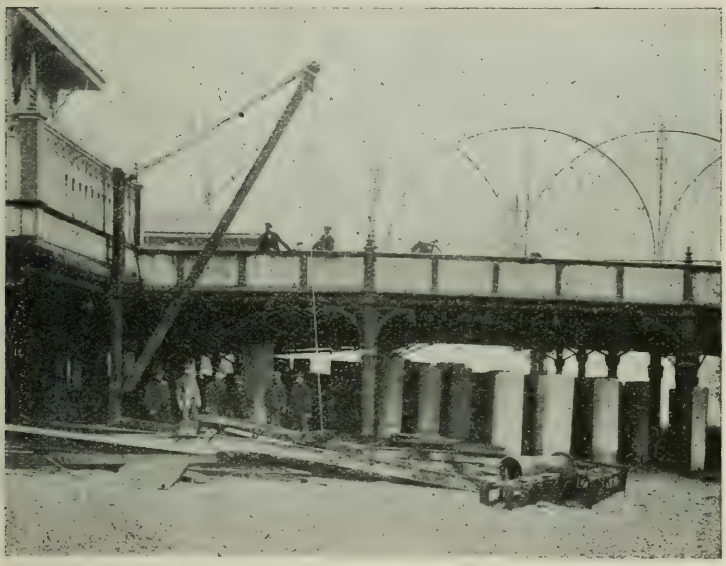

FIG. 18.—West Pier, Brighton.

beam for the stress over the support, this makes the beam no stronger than a beam of one span supported at the ends. This does not accord to reason, because in the two-span continuous beam there are two resistances, one at the centre and one at the haunch, while for the supported span there is only the one resistance. It seems unreasonable to ignore part of the resistances in continuous beams of equal resistances, and then when a continuous beam is designed according to ordinary formulæ and the resistances according to the stresses

thus obtained, to use the full value of the resistance as is customarily done.

A continuous beam is practically an arch. In an arch the ends are vertically and horizontally fixed, while in a continuous beam the ends are usually taken as only fixed vertically. In both cases there may be several points of contraflexure. With arches there is no limitation by rule as to point of contraflexure ; why, therefore, should there be such limitation for continuous beams?

Fig. 19.—West Pier, Brighton.

Fig. 18 shews reinforced concrete cylinders used for the Brighton West Pier landing stage, and Fig. 19 shews cylinders ready to be placed in position. Fig. 20 is another view of the landing stage ; this stage was constructed of rolled steel joist piles driven into the ground and with rolled steel joist and [struts and beams and round steel tie rods. The piles were driven into the chalk to a depth of about 8ft. In the landing stage which this was replacing, it was found that the piles corroded very rapidly at the point where they entered the ground and usually broke off at that point.

In the reconstruction of the landing stage it was decided to protect this part by concreting round the piles. For this purpose cylinders about 2ft. in diameter and about 6ft. long were made with dovetail corrugated sheeting; these were rendered on the outside in sand and cement; they were then put over the piles and dropped on to the chalk, and a hole was then made in the chalk with the water jet round the pile for the depth of 3ft. The cylinder entered this hole the full

FIG. 20.—West Pier, Brighton.

depth of 3ft., it was then concreted on the inside and the hole outside, round the cylinder, was also concreted. A diver had to be used for this work. The author, who is Consulting Engineer to the Company, inspected some of these shields about a year ago and found that they were in good condition. Other work similar to this, but on a larger scale, was done to several piles under the Pavilion where dovetail corrugated sheets were used in a somewhat similar way.

One important development in the use of dovetail corrugated steel sheeting which has been made in recent years is for railway carriage floors, 22 gauge, $\frac{3}{4}$in. in depth being

used. The span varies, the maximum being about 3ft. 9ins. The sheets, which are galvanised, are put on and bolted to the frames of the railway carriages and a special composition is put on the top of the sheets, which are covered ½in. in depth. A large number of railway carriages have been thus dealt with, and have given great satisfaction. Only the under side of the sheets is treated or protected by painting.

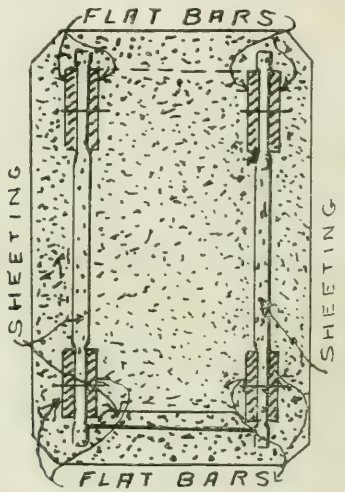

FIG. 21.

building. It seems that there should be a great opening for this material in shipbuilding. For the skin of the vessel the sheets can be joined together by lapping or welding, and be made perfectly water-tight. The strength can be increased by putting bars across or at right angles to the corrugations of the sheets, so as to form a square or rectangle that will take stresses in both directions. For a square slab supported on four sides the moment is $\frac{WL}{24}$ instead of $\frac{WL}{8}$, that is to say, three times the strength of one supported on two sides only. This is the French rule, and the author

considers it correct. Continuity in both directions will still further increase the strength of the sheeting. Concrete need only be put on the outside for the thickness necessary for the calculated stresses.

For $\frac{3}{4}$in. sheeting, 22 gauge, no concrete is needed on the inside, as the safe strength previously mentioned for 4ft. spans supported on two sides is 108lbs. per square foot. It seems, therefore, that the skin of a reinforced concrete ship constructed on this method would be lighter than any other. For bulk-heads this material seems invaluable, and also for decking and deck buildings.

The deck buildings could be constructed after the vessel is afloat, and so could some of the bulk-heads.

FIG. 22.—The Mizen Head Bridge, Ireland.

This system would save a great deal of trouble in confined spaces, as there is no shuttering required. It is very difficult in confined spaces to get the shuttering out without breaking it up. When dovetail sheeting is used for the skin of ships the frames can be made of either steel or reinforced concrete.

Aeroplanes.

Ordinary corrugated sheeting is now being used for aeroplanes, presumably for the larger types. Dovetail corrugated sheeting can be used for the same purpose, with the advantage that for equal weights the dovetail sheeting is stronger than ordinary corrugated sheets in the ratio of 4 to 3, which would be a great advantage.

Mizen Head Bridge.

The Mizen Head bridge was erected to provide access to Cloghan Island at Mizen Head, the extreme south-west

point of Ireland, on which the Commissioners of Irish Lights have built a fog-signal station.

The island is separated from the mainland by an inlet to the sea, and the site chosen for the bridge necessitated a span of 172ft. at a level of 150 above the sea. Designs were called for, and Mr. C. W. Scott, Engineer to the Commissioners, chose the design sent in by the author for a bridge in reinforced concrete. The concrete bridge was preferred to the steel bridge, for which several cheaper designs were sent, as the maintenance of the latter would be so costly

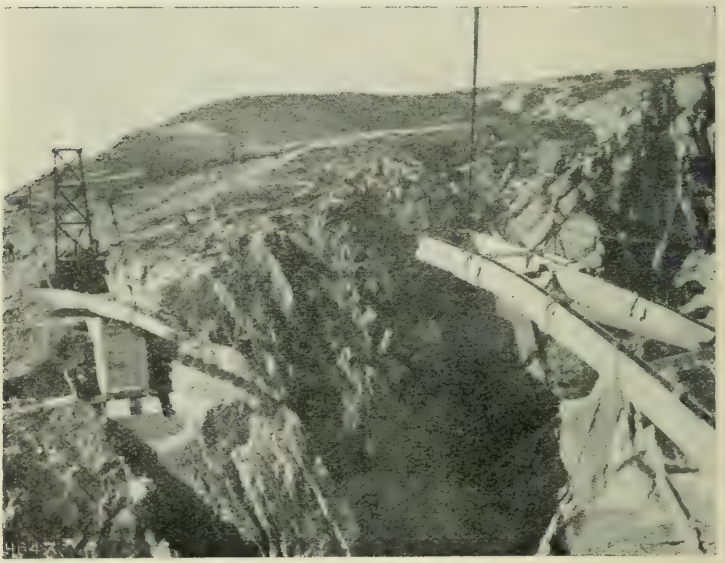

FIG. 23.—The Mizen Head Bridge, Ireland.

and the life so short in such an exposed position, where the bridge is often smothered with spray, and where wet fogs are prevalent.

The contract was placed in the hands of Messrs. Alfred Thorne & Sons, of Westminster. The bridge is 172ft. long in one span, and is of the through arch type. The ribs are parabolic curves with a versed sine of 30ft. and are of rectangular section 3ft. by 1ft. at the springing and 1ft. 6in. by 1ft. at the crown. The ribs are parallel in the centre

portion at 5ft. 6in. centres, but where the footway comes through at the quarter span they splay out, being 15ft. centres at the abutments and are connected by wind-bracings. This is to give stability under pressure, as the bridge is so narrow.

The footway is 4ft. 6in. wide between the horizontal beams, and is 5in. thick at the centre, including the granolithic surface; the beams are 15in. by 9in., and the reinforcement is made continuous from end to end by rigid connections and is anchored to the rock on either side to stiffen the bridge under unequal loading.

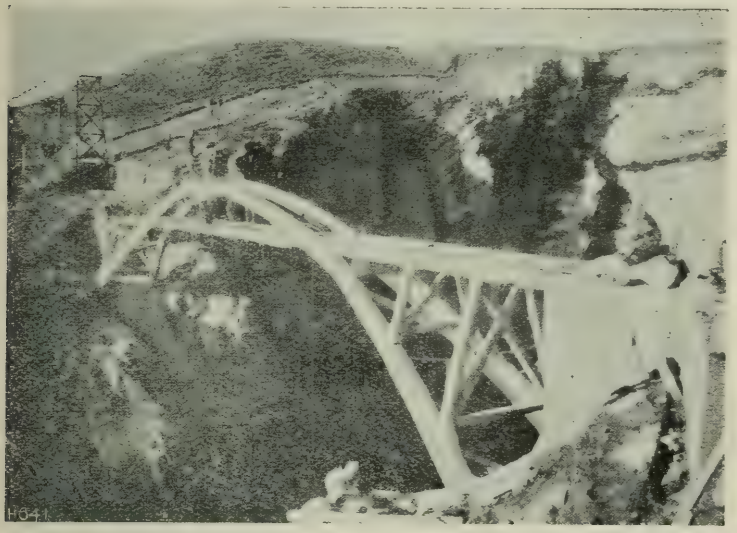

FIG. 24.—The Mizen Head Bridge, Ireland.

The trestles and wind-bracings are 9in. by 9in. section, and the hangers 9in. by 6in. The handrail is of reinforced concrete with 4in. octagonal rails, and posts 9in. by 6in. to 6in. by 6in. The rock on either side is benched out to receive the concrete abutments in which the ribs are bedded.

The novel feature of this bridge, apart from its great span (which is believed to be the greatest yet attempted in the British Isles) and its height above water, is that it was possible to erect without centering, thus effecting a great saving in cost.

The ribs were made in four portions, all on shore, and then built out from the abutments. They were in the form of a trough open at the top and connected with stirrups to prevent spreading.

The trough consisted of dovetail corrugated sheets placed with the dovetails in the direction of the depth of the trough for the sides, and across the trough at the bottom. The eight flat bars forming the longitudinal reinforcement were then bolted to the sheets, as shown in sketch (Fig. 21).

FIG. 25.—The Mizen Head Bridge, Ireland.

The outside of the trough was then rendered or concreted. The ends of the eight bars of the trough were provided with holes so that cover plates could be put on and bolted, thus rigidly connecting the different portions of the ribs together.

The wire rope-way was used to place the various parts in position, and the ribs were tied back to the rocks with wire ropes and temporarily stiffened.

The wind bracing was then fixed, and the ribs filled in, spaces being left to act as temporary hinges; the trestles

and beams were then put in place. All these parts had been previously cast on shore. The floor and hangers were shuttered and made *in situ*, the shuttering being supported on the completed beams. On completion the exposed joints on the outside of the ribs were concreted or rendered.

The bridge was tested two months after completion by loading with broken stone, to a super-load of 150lbs. per square foot, the load being gradually advanced from one end until the whole surface was covered, and it was afterwards removed in the same way, thus testing under the most unfavourable conditions. The maximum deflection was about one-fifth of an inch. The bridge has also stood the test of some very heavy gales.

Fig. 22 shews the completed bridge, and Figs. 23 to 25 shew the bridge in course of erection and the cableways used in its erection.

The greater part of the above description of the bridge is taken from "Concrete" (November, 1910), as also are some of the photographs. The author tenders his thanks for the kind permission to use this description of the bridge, which had been drawn up by Mr. P. H. Thorne, a member of the firm of contractors.

Historical Notes.

The machine for making the dovetail corrugated sheeting was invented and patented by Mr. A. O. Wright in 1893. Messrs. Hugh L. Cunnah and Henry A. Hughes invented and patented certain methods of application for the dovetail corrugated sheeting. The partitions made with dovetail corrugated sheets and H and channel irons were known as the "Cunnah-Wright Partitions." The further development of the sheeting for reinforced concrete and other work now known as the "Lewis System," is due to the author, ably assisted by the late Mr. Percy Dawkins, who for many years acted as manager to the Lewis Construction Co.

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THE CONCRETE INSTITUTE :

AN INSTITUTION FOR STRUCTURAL ENGINEERS, ARCHITECTS, Etc.

Paper to be read at the Eighty-fifth Ordinary General Meeting of the Concrete Institute on Thursday, February 27th, 1919, at 5.30 p.m., at Denison House, 296, Vauxhall Bridge Road, Westminster, S.W.1 (close to Victoria Station), and CONFIDENTIAL *until after the Meeting. The paper is copyright, and is not for publication.*

Industrial "Safety First."

By Mr. EDWARD WILLIS, F.S.I., A.M.Inst.C.E., M.I.Mech.E., F.R.San.I., Etc.

(Member of the London "Safety First" Council.)

The subject of this paper is well worthy of the closest attention by all, and the Concrete Institute is to be congratulated upon having decided to place before its members some aspects which may appeal to them in connection with their work, as well as a wider view of the whole matter as it may affect the industrial world in this country in the future.

The first principles of "Safety First" are implanted in the brains of all classes of animal life, and Nature has endowed such animals with various means of combating the many perils which beset them from the day of their birth until they cease to live; but with the human being the circumstances and conditions of life are to some extent unnatural, and therefore those principles which might be implanted in the brain of primeval man have through successive ages gradually been blunted by association with what we term "civilised conditions."

It therefore necessitates civilised man taking various precautions to avoid those dangers from which in many cases instinct (had he possessed it) might have protected

him, and it is for this reason that the London "Safety First" Council, realising the loss of life which by systematic and reasonable precautions might have been avoided, is using every effort to educate the masses to the importance of elementary principles, which if properly planted in the human brain will to some extent replace the missing sense of instinct, and enable the individual subject to avoid danger more or less automatically and thus save life and injury.

There are of course many ways in which accident or loss of life may be prevented in the industrial world, but these may be summarised for the purpose of discussion under the headings of:—

(*a*) Proper precautions during the erection of industrial buildings.

(*b*) Measures for the prevention of accidents during the period industrial buildings are in use.

(*c*) Measures for lessening the severity of accidents which may arise by reason of unforeseen causes or neglect of "Safety First" principles.

It is principally with the first of the foregoing that the constructive members of the Concrete Institute will most likely have to deal in their future professional or business capacities; and whilst in a paper of this character it is desirable to foreshadow to some extent the whole programme of "Industrial Safety First," it may be of greater interest to those present to outline more particularly a few of the various phases of the subject as particularly applicable to them.

In the inception of an industrial building, preliminary surveys of the site and subsequently the preparation of plans are matters of purely professional interest, and should the site be in the country, but few questions on this important subject are likely to arise.

The author, however, has realised in the course of more than thirty years' experience, that even in this section anxieties and protective measures are met with, which may be justly entitled to come within the term "Safety First."

All industrial sites of any magnitude are now arranged for, whenever possible, alongside of a railway, a river, a canal, or an important highway, in order that the best possible facilities for the transport of goods may be immediately available.

In surveying for the preparation of plans, special caution should be given to the chain man, when taking sections of a railway for the design of sidings, as all railway

companies, when issuing passes, repudiate any liability of accident and loss of life, and it was the author's misfortune to be connected with one case where, through the neglect of proper precautions, the chain man unfortunately lost his life.

In the case of a river or canal, it is known that the unexpected sometimes happens, and for checking soundings or levels, stable boats should always be provided, preferably of the flat-bottom type, and sufficient assistance be available with the necessary lifebelts, ropes, stretchers and First Aid appliances in case of overturning or drowning.

Surveying on a business highway or main thoroughfare needs the greatest caution in these days of motor traffic, and whilst the assistant in charge of such work is primarily responsible, it is the principal of a firm who neglects to issue and take proper precautions who may become morally liable for many of the accidents which may occur!

In the drawing office the preparation of drawings and calculations gives only a limited scope for the consideration of our subject, but it should not be neglected even in such apparently safe places, since insufficient lighting and unsuitable desks or drawing tables are harmful and lead to eyestrain, or even sometimes to permanent deformities and blindness, whilst mental work of any kind when unduly carried to excess leads to mistakes which, if proper care had been exercised, would in most cases have been avoided; and it must not be forgotten that a mistake in important calculations, which may even pass the man checking, if he is equally strained, might subsequently result in serious loss of life during tests, even if the buildings were otherwise unoccupied.

The foregoing has briefly dealt with a few points affecting the professional side of your Institute, and the importance of avoiding undue mental strain is equally applicable to the surveyor when taking off and checking quantities, which are usually accomplished in an incredibly short space of time, often involving night work to an unnecessary extent if proper organisation is not in existence.

Assuming your industrial building plans are approved by the proprietors and by the Local Authority, the contractor then first appears on the scene, and, should he be of a practical character, this may now be considered the trend of the subject as applying to the business side of the Concrete Institute.

The laying out of a factory involves the erection of various temporary buildings, such as resident engineer's office, clerk-of-works' office, covered and lock-up store-rooms, mess-rooms and lavatories for men, and in many cases a similar provision for women, since there is every probability that in the future it will be found that women who have been employed in industrial pursuits will not easily be removed therefrom, if the contractor finds their services equal to men; and in some work women are often found to be more painstaking and to give closer attention to results.

Industrial "Safety First" necessitates that the position of the foregoing buildings should be most carefully determined, as in a large contract there is often a continual stream of men, women, horses, carts, vans and motors going to and from various parts of the site and the offices; and should the latter be badly placed, accidents may probably occur, whereas if suitably placed, the crossing of main roads to the different parts of the site will be largely avoided, and persons will reach the lavatories, mess-room and stores at comparatively no risk of injury.

The character of these rough routes is also a matter for consideration. Careful contractors wisely provide a most carefully constructed sleeper road and efficiently maintain the same during the whole progress of the works, whilst others totally ignoring "Safety First" principles provide a rough hardcore, clinker, or rubbish road, often on a clay soil, with no thought of accidents to persons or strain to horses drawing heavily loaded vehicles in the quagmires often met with in such cases during winter. Thus, horses and vehicles get mired, crowds collect, and when the horse is goaded practically to madness at the final release, accidents cannot sometimes be prevented, whereas this would all be obviated by the foregoing elementary "Safety First" principles being adopted.

Industrial buildings, especially where heavy engineering foundations and tall chimney shafts are provided for in the scheme, usually involve the excavation of deep and wide trenches, and in some cases large openings. Here again is a source of danger which has been the cause of many fatal accidents. "Safety First" principles will obviate all this. What do they imply? The most careful selection of properly designed supports in the sides of the excavation, either by timber, sheet piling, proper poling and strutting, or in many contracts patent interlocking steel piling which can be used over and over again with practically complete

safety and at a lower cost after the initial capital expenditure.

Too much care cannot be exercised in the design and in the application of the support to the sides of excavations, and as the author has repeatedly seen the folly of carelessness in this respect, he makes no excuse for emphasising the point in a "Safety First" paper.

The provision of concrete foundations is invariably a more or less simple matter, but again the elementary principles of "Safety First" are necessary to ensure freedom from accident.

The provision of proper shoots for the concrete, and the elevation of the outlet of same as the concrete rises, thus giving a nearly equal distance from such outlet to the live concrete, avoid unequal splashing and consequently lead to safety by lessening the risk of accident; whereas serious alterations in the method of discharge may result in workmen hitherto prepared for existing conditions being taken unawares by the entirely different conditions of discharge, and thus liquid cement is splashed into the eyes, and claims for injury result.

It may be argued that the contractor always protects himself against such claims by means of insurance, but as an exponent of "Safety First" principles, the author would point out that every time an efficient workman is changed or suffers an accident, a certain amount of dislocation is liable to ensue resulting in loss of time with consequential inefficiency, and in addition there is always the personal loss and risk to the individual workmen.

Concrete mixing by hand when cement is used is a fairly simple matter, but if mechanical concrete mixers are used the ordinary principles of protection of moving parts should be adopted where the concrete is mixed on a more or less stationary platform. When the deposit of same is practically on the level, barrow runs become a *sine quâ non*, and here again precautions against accidents on "Safety First" lines should be adopted.

Barrow runs at considerable elevations should never be by the single plank, although often adopted, when within a foot or so off the ground, with comparative safety. The best elevated run is by five running planks tightly fixed together by under-bracing, and these can be used at fair elevations with comparative safety even if not railed; but the author strongly advises that such runs, when likely to be in use for a considerable period during erection, shall be

protected with a railing on either side; and again, in the erection of such railing it should not be a sham, but should consist of two bars and be sufficiently stable and strong to withstand at least the weight of two men's bodies against same. It might be argued that these precautions are elementary and are always adopted, but the majority in this room must know that in practice this is not so, and it is these and similar principles of "Safety First" which would successfully add to efficiency and the health and happiness of the workers when properly adopted and invariably provided.

In reinforced concrete another element of danger is at times present. Ordinary round bars so largely used in reinforced concrete construction are usually safe to handle whether clean or rusted, but certain very useful classes of metal, such as expanded metal of various kinds, split bars, and metals of a similar character are at times extremely awkward to handle even by an expert, and too much care cannot be exercised in at once dealing with an injury such as a torn finger or palm of the hand, since if the worker is healthy and the wound at once cleaned, no serious danger may result; but if work is continued and the wound much damaged and allowed to become foul, a case of blood poisoning might arise which may not only involve a large claim, but also loss of hand, arm, or even life. Cases of overstrain through lifting heavy bars have fortunately not come within the author's past experience in this class of work, but it is not an impossible consideration, and cautions in regard to same can well be issued with a view to its avoidance, especially when such bars are to be fixed in an upright position, and insufficient help is provided. The wiring together of reinforcing rods is another section of the work which sometimes leads to what are usually classed as slight accidents to fingers and hands, but the same advice applies, viz., the immediate cleansing and protection of the wound. Of course, the avoidance of such wounds can usually be effected by heavy leather gloves and the use of proper tools, but it is a moot point if the former are always warranted when proper caution is given and care exercised.

Probably the most important section of the work by members of your Institute is in regard to the centering and shuttering necessary for reinforced concrete structures, and no paper before your Institute on "Industrial Safety First" would be complete without some reference thereto. Unlike brick or stone structure, centering or shuttering is

required for walls as well as arches and floors in reinforced concrete, and in all vertical or steeply inclined structures double shuttering becomes a necessity.

Reinforced concrete centering in some elaborate industrial buildings is becoming practically a specialised work, the ordinary carpenter or joiner being far less efficient in its preparation than the less skilled man at ordinary building work who has however been continuously engaged for some years in this particular class of construction.

Vertical centering or shuttering requires very little external raking support as a general rule, and if carefully designed may usually be erected with none on one side and only sufficient to keep same vertical on the other. It is, however, in the disposition of raking supports where "Safety First" principles must prevail; and again in the design of the bracing and position of the connecting bolts between the front and back shuttering, care should be exercised in order that the same are placed in such position and are of such a size as to withstand the maximum stress when the concrete is in its semi-liquid form.

Most designers construct their reinforced columns, as far as possible, by means of shuttering in certain vertical removable sections, and then the inner spaces can be filled in usually without any raking supports; in the case, however, of floors structural supports become imperative. These may be brought up continuously from the ground or basement floor, and wherever possible, if the building is rising rapidly, struts should be in the same vertical planes as the struts below them, and where not so placed, care should be exercised that the base support is of such a size as to spread the weight of the concrete superstructure sufficiently over a suitable area.

Where heavy beams are being constructed no false economy should be exercised in making the centering supports absolutely firm and free from movement, since a secure centering, not touched until the concrete is thoroughly set, is a source of ultimate strength to the final structure.

It is often desirable to support the centering of floors from above the upper surface by means of bolts through the floor, the supports being thrown on to previously constructed beams, and this method has much in its favour.

What, however, is the most important consideration in regard to the "Safety First" principle is as to the period of time when the centre should be first removed and the structure loaded. Too much caution can never be exercised

in this section of the work, since in the author's opinion, and probably in the opinion of most architects, engineers and contractors in this room, failures have resulted over and over again by reason of centering being struck before the concrete has obtained sufficient strength. "Safety First" therefore emphasises the necessity of reasonable delay in the striking of centering, and still more reasonable delay in the test loading of reinforced concrete structures.

Assuming that the foregoing principles have been adopted, which is already done by many humane and capable contractors, the final testing of the structure, if erected to correct designs and with proper materials, may involve only a slight anxiety and but little danger; but to err is human, and it is the human element in reinforced concrete which, in the author's opinion, is the only bar to its universal adoption.

Each floor to be tested should have been certified by the resident engineer, clerk-of-works and foreman to have received in the proper position its full quantum of reinforcement, and then the test load should be applied as directed by the specification, but the most careful consideration should be given to such loading before proceeding therewith. It is most important that no isolated portions of a structure should be unduly loaded without some consideration being given to the effect of such load on certain adjoining parts of the structure.

It might at times be reasonable that a floor, calculated for 20 tons in regular work with a test load of 40 tons specified, should not be loaded with such excess load, unless the adjoining parts of the structure were proportionately loaded, so as to counteract any buckling effect on the columns immediately below. This risk, of course, should not arise in industrial buildings, not subjected to unreasonably heavy loads; but where the minimum reinforcement has been adopted, caution in test loading appears to be a necessary "Safety First" principle.

In the foregoing the question of "Safety First" has been considered more particularly in regard to reinforced concrete structures during erection, since these buildings are erected usually with a minimum of scaffolding, but a maximum of shuttering. In actual practice, however, at present the majority of buildings are erected structurally of brick, stone, or steel, and the precautions to be taken for the safety of workers thereon are equally important.

One of the problems in the erection of an important factory or building of any kind is the provision of perfect scaffolding and appliances, and much could be written about this particular subject.

Two simple illustrations coming within the author's personal experience on a large factory will illustrate this point. In the construction of a large gable the pediment base stone weighed approximately 1½ tons; he observed the men raising such stone with an ordinary 2¼in. circumference rope, and at once remarked to both the engineer and the foreman that the rope was liable to break, and that a heavier section or a new length of rope should be used; but the foreman affirmed that it was absolutely sound and perfectly safe. The author, who was the resident engineer at the time on the particular work, took the precaution to warn the man at the base who was guiding the stone to keep well clear of same, and the man at the top of the scaffold, 40ft. above, to be equally careful. An inspection of the building was then made whilst the stone was being slowly hoisted on to the scaffold. Upon returning to this part of the factory he found the block in question had been raised about 39ft., and the foreman turned to him remarking that he was right as regards the strength of the rope, when at that very moment there was a loud report and the stone dropped, the result being that the heavy sleepers upon which it originally rested were crushed like matches, and the man on the scaffold who was guiding the fall had the skin and flesh torn from his hands by part of the rope being drawn rapidly through same.

If "Safety First" principles had been adopted such an accident would have been impossible.

The second illustration was on the same factory. The chimney shaft, upwards of 200ft. high overall, was being erected, the first portion with an outside scaffold, the remainder being built from the inside. Shortly before completion the author warned the contractors that the work would have to be stopped, if the rope was not replaced by a new one, as he could accept no responsibility if a new rope was not at once purchased and put into use. Accordingly, the following day a new rope arrived, but with the usual procrastination the builder decided that he could not afford to lose his Saturday morning's work and said he would replace it after the bricklayers had left.

He also was warned of the risks which he ran, especially as the author had been drawn up daily by the rope in

question and knew its exact condition. After visiting certain other works he returned, but to his surprise found the works stopped, when it appeared that a load of bricks had started its journey up the chimney shaft and the inevitable had happened, viz., the rope broke and the bricks dropped. Fortunately, however, in this case no one was injured and only inconvenience and damage resulted. It was, however, not an entirely satisfactory feeling to the men at the top of the shaft who had to come down, or to the author, who had been raised 170ft. by the rope in question only a few hours before it broke.

A frequent source of danger in scaffolding is the projection of scaffold boards over the ends of the putlogs or ledgers, whilst another is insufficient strength of a scaffolding to withstand safely the weight of heavy iron girders, stones, or bricks.

When a thoroughly reliable foreman with a wide experience and imbued with consideration for the care and safety of the workmen under him is employed, accidents are usually few and far between, and even those which do occur are more often caused by the carelessness of the workmen themselves than by any defect in the scaffolding provided by the contractor, or in the carrying out of the obligations thrown upon him.

One cannot, however, too strongly impress on less thoughtful contractors the moral responsibility that must always rest upon them in regard to the safety of their workmen, since whilst one admits compensation is usually paid should an accident occur and the workman be maimed for life, yet the responsibility of such maiming, if it occurs by reason of a contractor's neglect or false economy, is a moral obligation which cannot be cancelled by any insurance.

There are many other causes of accidents which must occur to the minds of those present, and it is with a view of avoiding such in the future that "Industrial Safety First" principles should be instilled into the mind of every employée as well as the employer. If the London "Safety First" Council succeeds in saving the lives of only a few workmen or other members of the public its mission has not been in vain, but the author is convinced that "Safety First" and welfare measures are so allied that the movement will spread in ever-widening circles.

MEASURES FOR THE PREVENTION OF ACCIDENTS WHEN INDUSTRIAL BUILDINGS ARE IN USE.

There are so many Government departments controlling the question of accidents, illness or injury in industrial undertakings that it may seem both presumptuous and redundant to discuss this matter, and the author therefore proposes to make only a few observations upon the subject as a whole and endeavour to stimulate interest in this section of "Industrial Safety First." Machinery is gradually coming into its own, and must do so more and more now that the price of labour is continually on the increase. It may be therefore anticipated that industrial work will in the future be carried out by mechanical power much more than in the past, and the physical human element will be eliminated as far as possible, only a strictly limited number of employées being engaged upon many industrial works.

There are, however, certain industries which must of necessity employ a large number of hands, and in this connection there is not only the danger from carelessness in connection with running machinery, but there is a risk of ill-health or even death from the actual materials or products of the materials handled, whilst there is always the danger of fire in factories and explosion from fire in badly ventilated mines.

In the steel grinding and allied industries one has to combat injuries to the pulmonary organs of the employées arising from the steel filings or minute pieces of emery or other grinding materials; workers in the wool industry also suffer from diseases by handling the wool of animals infected by anthrax and the risk of lung troubles from the minute portions of wool floating in the air; whilst in the sulphur match and lead industries equally serious illnesses from poisoning may result if proper precautions are not taken to prevent same.

The Government in its wisdom has wisely adopted some "Industrial Safety First" precautions, although not mentioned under that heading, and has extended same during the war by "Welfare" institutions; but is this sufficient? Serious illnesses and deaths still occur; the death rate of workers in certain trades is far greater, and the duration of life is far below what it should be. This can only be lessened or avoided by the worker himself systematically adopting safety precautions, and the author is strongly of

opinion that "Safety First" principles must be encouraged in all from early childhood, and regularly taught in all schools. Prior to modern times the child was obedient to his parent and his teacher, and whilst modern means of protection were unknown, prompt and ready obedience lent itself to safety; but the modern child and the modern worker have taken up a somewhat different attitude of thought and action.

Whilst some workers recognise that both legislation and the moral obligations of an employer make him undertake "Safety First" precautions, the vast number of employées in most cases fail to realise that such precautions are even more to their advantage than to that of the employer, since they always involve expenditure to the latter, in addition to insurance premiums, and where the former are careless the results are of course not encouraging.

It will be seen from the foregoing, that the author is strongly of opinion that there must be still greater harmony between the employer and the employée; each should have the interests and welfare of both at heart, and if that principle is really adopted, not only will "Safety First" become *un fait accompli*, but even national safety and prosperity will be extended.

MEASURES FOR LESSENING THE SEVERITY OF ACCIDENTS WHICH MAY ARISE BY REASON OF UNFORESEEN CAUSES.

Before concluding this paper the author desires to add that in his opinion "Safety First" principles are not confined to the prevention of accidents.

Accidents will occur even when no neglect of employer or carelessness of employée is apparent. It therefore becomes necessary to have men always at hand to deal with accidents which may occur from some unforeseen causes, since prompt attention may not only save a person's life, but may also avoid such person being maimed for life.

As a first measure of "Safety First" principles under this heading, the author strongly advocates the further extension of the Welfare Centres in all industrial undertakings. When there is a distinct camaraderie among workers in the industry, volunteers are always ready and anxious to help when accidents have occurred and dangers must be faced to rescue the wounded. Take the illustration

of an explosion in a mine. To the honour of this country and of the mining industry, there has never been a case where other miners have not volunteered to risk their lives in saving their colleagues. Equally in other industries there have always been found volunteers, who will risk any dangers for the sake of their fellow-workers, and in support of such fine feelings the Welfare Section is doing a great work.

The provision of the St. John's Ambulance and British Red Cross lectures throughout the country, wherever sufficient men or women are willing to present themselves, is another factor in Industrial "Safety First." Knowledge taught at ambulance lectures has been the means of saving thousands of lives in this country, and the more this is taken up as a pleasure, and principles of safety inculcated in the minds of all, the more health and pleasure and the less illness will result!

There is a further means of "Safety First" which must not be forgotten. I refer to the Volunteer or paid Fire Brigade in all large industrial undertakings. It will be found that where the employer is willing there will invariably be employées who are also willing to give up their time and study the work of fire protection and extinction. It is, of course, not suggested that a Volunteer Factory Fire Brigade will be in all respects equal to the Brigade at a Branch Station of the Metropolis or other large city whole-time Fire Brigade; but the author has heard of cases where the employées of a factory have taken such an active interest in this class of work, which the employer has fostered and loyally supported, that they have been able to compete with local Brigades, and there is no reason why this very important section of the subject should not be largely extended. It is in the interests of the employer, as well as the employées, and competitions between large industrial firms' Fire Brigades would lead to such healthy rivalry, as would no doubt create Factory Brigades which would not only benefit their own factories in case of fire, but in case of a large town or city fire might prove of great use in saving life and property.

As a "Safety" precaution in case of fire there is nothing better than one of the "Sprinkler" systems now much in use, or electric automatic alarms throughout a building, working on a similar basis, viz., the melting of an alloy at some pre-ordained temperature in the neighbourhood of 150 degrees Fahr., which will at once set in motion

the main as well as subsidiary fire bells, and thus all in the factory may at once leave by properly arranged routes and exits, the roll being immediately called on the employées assembling in the pre-arranged position.

The author desires once again to emphasise the fact, that "Industrial Safety First" is not confined to the *direct* prevention of accidents, but covers all those indirect tendencies to carelessness in respect of mind, body and work which may in any way lead to ill-health or accident. Thus it involves the great issues of National Health, Child and Adult Welfare, Education and Housing.

National Health is affected inasmuch as by far the greater bulk of the adult population of this country is of the wage-earning class, and in the course of their livelihood the workers must instinctively or automatically exercise such care in "Safety First" methods, as will prevent the possibility of ordinary accidents, and they will thus be enabled to live in health and happiness.

Child and Adult Welfare is equally important; in fact it has been one of the growing responsibilities that the late Government felt itself called upon to undertake.

Child Welfare is undoubtedly the most advantageous, since if not undertaken it may mean a loss in A.1 physical and mental population, and consequential loss in national prosperity. The child is also more tractable, and more easily able to learn than the adult, and thus "Safety First" principles properly and consistently taught in early childhood would become nearly a matter of instinct when the child becomes an adult.

Adult Welfare, on the other hand, deals more particularly with trade, industry and the adults' daily occupation; since, if proper principles have been instilled into the children in regard to home matters, these principles will remain when they become adults; but in their occupation they are to some extent at the mercy of the employers, and therefore where the employer is not providing a model factory, the adult workers should prove by practice that "Safety First" and Welfare methods are equally advantageous to both employer and employées, and better work will be the result of organisation in this respect.

Education has hitherto been largely on the mental side, and only to a limited extent on the physical side. "Safety First" principles necessitate both; the "mental" to avoid disaster automatically, the "physical" intentionally to combat the same where it cannot be avoided. When the

proper admixture of the two forces is adjusted the learner should be perfectly safeguarded. It is, in the author's opinion, in education that great strides will be made in "Safety First" principles, and he looks forward to a great diminution in accidents, in the illness resulting from same, and finally to better health and prosperity in the population of the future.

Lastly, the question of *Housing* is one that cannot be omitted in a subject such as that being dealt with. The housing of the low wage earner has been sadly neglected in the past, and it has been apparently only this Great War and the intimate association into which the rich and poor alike have been thrown in the trenches that has at last broken down some of the barriers of class distinction and convention, and enabled all classes to realise that the workers of all grades and their children should have decent homes to live in.

Better housing, therefore, is essentially one of the indirect aids to "Industrial Safety First" and there seems every hope of this section of our subject being thoroughly and properly handled in the future.

The author had hoped to prepare a number of slides to illustrate the points and suggestions thrown out in the paper, but difficulties having arisen the Honorary Secretary has prepared a limited number from existing structural photographs, and it is hoped some additional slides kindly loaned by certain Reinforced Concrete firms will be shewn. He is also appending some statistics from Home Office reports which are sufficient in themselves to prove the absolute necessity and importance of the subject of "Safety First."

It is satisfactory to note that the new "Industrial Safety First" Association has been recognised by some of the largest firms in the kingdom, and with Lord Leverhulme as President, supported by an excellent Committee, there is every hope that there will be a large diminution in accidents in the future.

There are many other detailed suggestions which could be made, but sufficient has been said, it is hoped, to promote a useful discussion.

The author desires to thank the various concrete firms who have supplied him with certain information.

APPENDIX I.

Reported Cases of Poisoning in 1914.

Disease and Industry.	Adults.				Young Persons.				Children		Total.	
	Casualties.		Fatal Cases.		Casualties.		Fatal Cases.		Casualties	Fatal Cases.	Casualties.	Fatal Cases.
	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.				
Lead Poisoning ...	415	23	27	1	4	3	—	—	—	—	445	28
Mercury Poisoning ...	9	—	—	—	1	—	—	—	—	—	10	—
Phosphorus Poisoning	—	—	—	—	—	—	—	—	—	—	—	—
Arsenic Poisoning ...	2	—	1	—	—	—	—	—	—	—	2	1
Anthrax	43	3	6	1	5	2	—	—	1	—	54	7
Total	469	26	34	2	10	5	—	—	1	—	511	36

APPENDIX II.

All Reported Accidents, 1914: Causation.

Causation.	Accidents.		Dangerous Occurrences.
	Fatal.	Non-fatal.	
Machinery moved by mechanical power	427	42,596	2,150
Machinery not moved by mechanical power ...	13	1,947	—
Struck by falling body	121	24,142	—
Persons falling	401	19,160	—
Struck by tools in use	7	6,598	—
Fire	4	60	445
Other	314	63,623	—
Total	1,287	158,126	2,595

APPENDI

All Reported Accidents in 19

Industry.	Adults.				Young Persons.		
	Casualties.		Fatal Cases.		Casualties.		Fa
	Male.	Female.	Male.	Female.	Male.	Female.	Ma
Textile Factories	6,150	3,611	53	11	2,192	2,251	12
Non-Textile Factories ...	104,065	4,456	803	7	21,608	3,250	71
Workshops	45	11	4	—	10	6	—
Places under s.s. 104-105	11,165	50	302	3	168	16	13
Total	121,425	8,128	1,162	21	23,978	5,523	96

All Reported Accide

	Machinery moved by Mechanical Power.		Molten Metal. Hot Liquid.		Explosion.		Escape of Gas or Steam.		Electricity.		Machine Cranes.	
	Casualties.	Fatal Cases.	Casualties.	Fatal Cases.	Casualties.	Fatal Cases.	Casualties.	Fatal Cases.	Casualties	Fatal Cases.	Casualties	F C
Textile Factories	7,127	45	257	—	34	—	43	—	10	—	14	
Non-Textile Factories ..	33,693	303	6,087	44	946	40	945	28	413	21	631	
Workshops	1	—	6	—	—	—	—	—	—	—	—	
Places under s.s. 104-105	2,202	79	22	—	21	2	22	2	11	—	62	
Total	43,023	427	6,372	44	1,001	42	1,010	30	434	21	707	

APPENDIX III.

ALL REPORTED ACCIDENTS IN 1914, GIVING INDUSTRY AND SEX.

	Adults.				Young Persons.				Children.		All Ages.				Total.	
	Casualties.		Fatal Cases.		Casualties.		Fatal Cases.		Casualties		Casualties.		Fatal Cases.		Casualties.	Fatal Cases.
	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.		
es	6,150	3,611	53	11	2,192	2,251	12	3	208	94	8,550	5,956	65	14	14,506	79
ctories ...	104,065	4,456	803	7	21,608	3,250	71	5	50	7	125,723	7,713	874	12	133,436	886
... ...	45	11	4	—	10	6	—	—	—	—	55	17	4	—	72	4
s. 104-105	11,165	50	302	3	168	16	13	—	—	—	11,333	66	315	3	11,399	318
... ...	121,425	8,128	1,162	21	23,978	5,523	96	8	258	101	145,661	13,752	1,258	29	159,413	1,287

APPENDIX IV.

ALL REPORTED ACCIDENTS, 1914, INDUSTRY: CAUSATION.

ten Metal. t Liquid.		Explosion.		Escape of Gas or Steam.		Machinery not moved by Mechanical Power.						Struck by Falling Body.		Persons Falling.		Struck by Tools in Use.		Other Causes.		To l.	
						Electricity.		Cranes.		Presses for Metal Articles.											
ties	Fatal Cases.	Casualties.	Fatal Cases.	Casualties.	Fatal Cases.	Casualties	Fatal Cases.	Casualties.	Fatal Cases.	Casualties.	Fatal Cases.	Other Casualties.	Casualties.	Fatal Cases.	Casualties.	Fatal Cases.	Casual-ties.	Fatal Cases.	Casualties.	Fatal Cases		Fatal Cases.
7	—	34	—	43	—	10	—	14	—	1	—	33	823	6	1,489	12	302	—	4,373	15	14,506	79
7	44	946	40	945	28	413	21	631	10	434	—	768	20,532	80	15,677	234	6,073	7	47,237	119	133,436	886
6	—	—	—	—	—	—	—	—	—	—	—	8	5	2	7	2	7	—	38	—	72	4
2	—	21	2	22	2	11	—	62	3	—	—	9	2,903	33	2,388	153	223	—	3,536	46	11,399	318
2	44	1,001	42	1,010	30	434	21	707	13	435	—	818	24,263	121	19,561	401	6,605	7	55,184	181	159,413	1,287

The Concrete Institute :

AN INSTITUTION FOR STRUCTURAL ENGINEERS, ARCHITECTS, ETC.

Paper to be read at the Eighty-second Ordinary General Meeting of the Concrete Institute, on Thursday, November 28th, 1918, at 5.30 p.m., at Denison House, 296, Vauxhall Bridge Road, Westminster, S.W.1 (close to Victoria Station), and Confidential *until after the Meeting.*

Presidential Address.

By H. D. SEARLES-WOOD, F.R.I.B.A., Etc.

Gentlemen,—I have to thank you for electing me as your president, an honour which I highly appreciate.

Glancing at the last Annual Report, I think you will agree, that it is satisfactory to find in these difficult times, that the membership is 981, as against 978 last year; if we can hold our own to the end of the war, I feel certain that we shall get a large increase in the membership when the demobilisation of the troops takes place.

There is a slight improvement in our financial position, but we are still greatly hampered by the want of funds. We have been able to issue further volumes of our Transactions, and to bring our work up, so as to include the papers read in 1916-17; we hope to keep up this issue of the papers read session by session in the future. It is to be regretted that we are unable to print the discussions on these papers at present, but the war conditions render this unavoidable.

The "Mnemonic Notation for Engineering Formulæ" and "Loads on Highway Bridges" are in process of publication, and we are making arrangements for the issue of sets of other papers in book form, but this is being hindered by the paper shortage.

The Board of Trade has printed a list of Timber Substitutes, compiled by the Concrete Institute, and to be obtained on application to the Secretary. This is only a first issue, and we invite all who wish to be added to the list of those making these substitutes, to communicate with the Concrete Institute, with a view to their names being added to the lists. The timber shortage appears to be so great that there must be a special need for such a brochure at the present time; and as the list is referred to in the "Board of Trade Journal," which circulates all over the world, the demand is likely to be very large.

The relations between architects and specialist engineers have been dealt with by the Concrete Institute in the following report:—

REPORT OF THE SPECIAL COMMITTEE OF THE CONCRETE INSTITUTE ON RELATIONS BETWEEN ARCHITECTS AND SPECIALIST ENGINEERS.

On November 18th, 1915, the Council of the Concrete Institute appointed the following as a Special Committee to consider and report upon the Relations of the Architect, the Reinforced Concrete Specialist and the Structural Engineer:—

Professor Henry Adams, President, C.I., M.Inst.C.E., etc.
Dr. Oscar Faber, D.Sc., Assoc.M.Inst.C.E., Chief Engineer of Messrs. George Trollope and Sons and Colls and Sons, Ltd.
Mr. H. D. Searles-Wood, F.R.I.B.A., Vice-President C.I., etc.
Mr. T. B. Shore, Manager of Considère Construction Co., Ltd.
Sir Henry Tanner, C.B., I.S.O., F.R.I.B.A., Past President C.I.
Mr. R. W. Vawdrey, B.A., Assoc.M.Inst.C.E., Engineer to Indented Bar and Concrete Engineering Co., Ltd.
Mr. H. Kempton Dyson, Secretary C.I. (Hon. Secretary of Committee).

The Committee held meetings on January 6th, February 24th, April 13th, April 18th, and June 15th, 1916.

Sir Henry Tanner was elected by the Committee to act as Chairman.

The increase in scientific knowledge in the nineteenth and present centuries has not left unaffected the construction of modern buildings, and at present there are very few buildings in which concrete and steel do not form important parts of the whole.

The calculations and detail designs for such structural elements necessitate the exercise of specialised engineering knowledge and involve considerable additional work beyond the duties of the architect. It is usual, therefore, to employ an engineer to design the structural steel or reinforced concrete portions of the buildings.

The employment of an engineer, to design such details of construction, does not mean that the architect's work is reduced in any way. Indeed, the architect has now more duties to perform than in the past, owing to the more complicated nature of buildings generally, involving the co-ordination of various specialist trades. Not only has he to prepare and direct the general scheme of building operations, to plan the buildings, design the æsthetic features and prepare the ordinary constructional details and specifications, but he has to see that the many by-laws and regulations are conformed to. These latter increase in number, while the law of building contracts in itself is becoming more intricate as time goes on, and the architect is generally required to occupy the position of a quasi-arbitrator between client and contractor.

The functions of the architect have changed with the progress of civilisation, and there are some differences in practice in different countries. In the Middle ages the designer and general superintendent of building operations was a master craftsman, employing labour direct. This still applies somewhat to-day in France and Germany and in the Colonies. Within modern times in England the architect acted as contractor, tendering in competition, even for large public buildings, by submitting a design and price at one and the same time. We still have contractors, prepared to submit designs for buildings complete with their price, but the practice is not generally considered to be satisfactory by clients, who wish to have their interests watched by one whose interests are entirely independent

The practice of architecture has thus become exclusively professional. In an allied way the practice of civil engineering has also become professional.

Originally the contractor had to take out his own quantities from the architect's or civil engineer's drawings, in order to prepare his price, and with a multiplication of competing contractors this meant considerable waste in duplication. In order to save this the profession of Quantity surveying came into being. Seeing that the preparation of the Bills of quantities is incidental to the contractor's pricing of the work and to the adjustment of variations and extras, the quantity surveyor's fees are part of the cost of construction, and are customarily included in the Bills of quantities for payment out of the contract sum, although in some cases the surveyor is paid direct by the client.

Other innovations in building practice have been the invention of fire-resisting construction, heating and ventilating apparatus, sanitary appliances, hydraulic and electric lifts and other mechanical plant. These features, which all require special design, were at first, and are still, largely supplied by inventors, acting as manufacturers and sub-contractors, and are often selected by architects and included in the Bills of quantities for payment out of the contract sum. With increasing knowledge architects have occasionally prepared the designs for such details, when they were quite simple, and have asked nothing for the extra work, whilst in other cases the manufacture of special fittings has become somewhat standardised, so that the cost of the design forms but a small proportion of the manufacturer's establishment charges.

In structural engineering each job is individual and there is little repetition. The cost of the designs for the details of reinforced concrete or structural steel work is therefore considerable; and when this work is multiplied, by several specialist engineers submitting competitive designs, the costs are largely increased and have finally to be met by the client in the form of increased charges, included in the tenders. Some specialist firms obtain their fees for design by way of profit on the steel work, which they sell; some again by selling patented forms of steel bars, others by sub-contracting for the whole work of manufacture and construction, and still others, by charging royalties or

fees, which are paid by the general contractor and included in his tender.

Competition in design and price has at the same time led to abuse, not only in respect to extravagance by duplication of work, or in the difficulty of securing the client's interests, in adjusting variations and extras, but in respect to the encouragement, which such a system gives to skinning and scamping in design and execution. It pays competing firms to take risks. The conscientious designer is at a disadvantage, and therefore the unscrupulous are often encouraged at the expense of those who are doing their best to supply what will efficiently meet the client's requirements. Yet the architect is called upon to bear the onus of failure; for he cannot evade legal liability for the design and supervision of such structural work, unless the designer of such details has professional status, properly recognised by the Building owner. Time is generally saved by the collaboration of the specialist engineer with the architect in the initial stages, which in itself makes for economy.

The following paragraphs from the American Institute of Architects' Memorandum on the professional practice of architects and schedule of minimum charges are worthy of note:—

> "The architect's professional services consist of the necessary conference, the preparation of preliminary studies, working drawings, specifications, large-scale and full-size detail drawings, and of the general direction and supervision of the work, for which (except as hereinafter mentioned) the minimum charge, based upon the total cost of the work complete, is six per cent.
>
> "The architect is entitled to compensation for articles, purchased under his direction, even though not designed by him.
>
> "Where heating, ventilating, mechanical, structural, electrical and sanitary problems are of such a nature as to require the services of a specialist the owner is to pay for such services. Chemical and mechanical tests and surveys, when required, are to be paid for by the owner."

The Committee considers that, when an architect desires to employ an engineer to design and supervise

the erection of reinforced concrete or steel frame construction, the client should pay an additional percentage on that portion of the work.

The rate of payment should be varied according to the amount of work entailed in the structural engineering design, specification and supervision; but, as a general indication, it is suggested that the additional fee to the specialist engineer should consist of a commission on the cost of the particular details which he designs. It is emphasised that the engineer's fees would only be charged on a portion of the work, rarely amounting to a third of the whole cost of the building.

As regards the supervision which is to be required from the structural engineer, it should be distinctly understood, as in the case of the architect, that such supervision is different from the continuous personal superintendence which may be secured by the employment of a clerk-of-works or superintendent of construction. The supervision by the engineer means such inspection (by himself or deputy) of work in process of erection, completion or alteration, or of work in shops, as he may find necessary to ascertain whether it is being executed in general conformity with his drawings and specifications or directions.

A clerk-of-works or superintendent of construction will generally be required, and such assistance should be employed by the architect at the owner's expense, the responsibility of the engineer being protected at the same time by the latter being empowered to require the discharge of the clerk-of-works or superintendent if he considers his work inefficient. Reinforced concrete in particular requires continuous attention from superintendents of special training and experience, and it may be necessary on works of magnitude to engage more than one clerk-of-works or superintendent to protect adequately the interests of the owner.

The Committee is of opinion that the rational procedure would be for the architect to select a specialist engineer, who should design the structural engineering work in consultation with him, and then to have Bills of quantities of the special work prepared by the surveyor engaged for the remainder of the work, so that all can be issued together. By this means fair tendering would be obtained and any variations could be properly priced. The architect's commission has hitherto

covered all the necessary services in the designing of a building, and it seems, therefore, that in some way this course should be continued, especially having regard to the architect's responsibility for the whole structure; because otherwise he would have difficulty in recovering from the engineer, as there would be no privity of contract. The Committee suggests, therefore, that the remuneration of the architect should take the form of some addition to the usual percentage, according to the character of the work—say 20% to 25%—wherever skeleton steel or reinforced concrete structures are used; and it has to be borne in mind that by the employment of an engineer the architect derives *some* saving in labour and expenses, but by the above suggestion practically the *whole* cost would be met.

It is not the province of the Committee to suggest what the remuneration of an architect should be; but it would seem that no single percentage can meet all cases, consequently its recommendation is for a percentage in regard to engineering works on the charge that would otherwise be made on the whole work.

I regret that the Royal Institute of British Architects has decided not to deal with this Report.

With regard to the specialist, there are several kinds; he may, for instance, deal in a patent article requiring special knowledge for its application to individual cases, such as some reinforced concrete systems. Again, the specialist may be the contractor, his services consisting not only of design but of execution, and here again special knowledge has to be adapted to individual cases; in this connection take the cases of heating and lighting systems. A third instance is a specialist product, such as elevators and labour-saving devices of the like nature. Again, there is the specialisation in a material, probably requiring expert chemical knowledge, such as waterproofing compounds, special pavings, etc. There is also the specialist who assists the architect in his work at a fee, as for instance the quantity surveyor or the constructional steelwork designer. There are varying degrees in each case, and it is impossible to draw a line between the various types involved; with regard to the work now commonly undertaken by specialists there is a broad line of distinction to be drawn between the following classes:—

(1) Work forming an integral and essential part of the structure, such as steel framework, or in a stronger degree, reinforced concrete construction.

(2) Work which is, to a greater or lesser degree, applied to or installed in the finished structure, such as heating, ventilating, and lighting systems, power installations, etc., and equipment generally.

With regard to the former, the architect's services in organising such matters are very onerous; and all architects cannot have detailed knowledge of all the work comprised in the second class, although many may have specialised in certain branches of each class in addition to their general architectural knowledge.

With regard to the first class, such work is a modern development of building construction and is so essentially a matter for an architect's personal attention, that his knowledge should be much more than superficial; and he should have given such matters as much study as if he proposed actually to undertake the work. The architect in these days must be a capable organiser, but there must be no danger of his degenerating into an organiser solely.

It is specialist work of the first class, that the Concrete Institute is strongly of opinion should not be the subject of competition in design; and I would urge it for the further reason, that inefficient design in constructional work can scarcely be detected until after the building is handed over or when an actual case of failure occurs; and even if it is discovered by testing or otherwise, the defect cannot be remedied without great expenditure and loss to one or more of the contracting parties. A failure will in any event cause extreme inconvenience and almost certain damage to the client and possibly bring great discredit upon the architect.

It is not sufficient for an architect to safeguard his client by merely drawing up agreements, etc.; he should be able to, and should actually, satisfy himself that the specialist's work is, in the circumstances, in every way suitable.

It is not possible to draw up a form of appointment for the specialist, which is applicable to all the varying conditions under which he is employed, but the following points should be borne in mind as to his duties:—

(1) He should prepare all plans, calculations, instructions and quantities necessary in the opinion of the

architect, and these particulars should be sufficient and adequate, and should be based on the architect's instructions.

(2) He should be responsible for the accuracy and efficiency of his designs, and for the strength and efficiency of the work carried out to his designs.

(3) He should carry out his work with due diligence.

(4) He should obtain the architect's approval for the whole of his work, such approval not to relieve him of his responsibility.

(5) He should be cognisant of and comply in all respects with the requirements and regulations of local authorities and other bodies under whose jurisdiction the work is to be carried out.

(6) He should undertake not to divulge any particulars or information furnished by the architect, or to publish particulars of the work in the Press or otherwise, without the express sanction of the architect.

(7) He should relieve the client and the architect from responsibility and cost in connection with the infringement of patents, and he should accept all liability in connection with the work executed to his designs.

(8) He should be prepared to visit the work during progress and after completion, and to make all necessary tests and give written reports from time to time as the architect may require as to the manner in which the work is being carried out.

On the subject of the second class, namely, specialist's work applied to or installed in the finished structures :—

There is great need for more intimate working between the architect and specialist so that the building is best adapted for the machinery or fittings installed. Speaking as an architect, I have found great difficulty in getting mechanical engineers to decide where they want to place their shafting and machinery, and I have often had to stop them cutting through essential structural members in the building. I suppose the chief reason is, that not sufficient time is given to the consideration of these things before the building is started.

The point that I wish to make is, that in all these

matters, the sooner the architect can come in touch with these specialists and agree on the way in which the various schemes are to be carried out, the better the building will be adapted to contain them and the smoother the carrying out of the work will be made.

Members of the Institute will, I am sure, be glad to have a resumé of our association, through the medium of the Science Committee, with the Department of Scientific and Industrial Research.

Commencing with the year 1914, the Institute got into touch with various laboratories, and, as a result, ascertained that about a couple of dozen were furnished with most of the necessary apparatus for making investigations upon concrete and other building materials. The question of finance was of course a prime factor in any such research; consequently in 1916, when the Advisory Council on Scientific and Industrial Research was organised, the Institute decided to make an appeal to it for assistance in carrying out the proposed work. On two occasions a deputation interviewed the Chairman and Secretary of the Council, and eventually (March, 1917) the sum of £830 was allocated for the year then current, being more or less the proportionate amount of the total expense which the research was expected to involve.

This investigation was to be made through the medium of various laboratories, the work being restricted to concrete and concrete aggregates. Our Institute was established as the maintaining body, and the laboratories undertaking the investigation were:—Birmingham University, Bradford Technical College, Cork University College, Dublin University, Edinburgh University, Huddersfield Technical College, Manchester Municipal School (now College) of Technology, Nottingham University College, and Salford Royal Technical Institute. Huddersfield and Nottingham withdrew at an early stage, war conditions adversely affecting them, but to the above list of laboratories we were subsequently able to add Cambridge University.

Of these ten laboratories, work of a more or less practical nature has been actually done by Birmingham, Cork, Dublin, Manchester and Salford; Cambridge, while being anxious to commence operations, came in only just prior to the stage of our receiving a communication from the Research Department to the effect that it did not see its way

to recommend a renewal of the grant for the year now current, for reasons stated in the correspondence, from which I give extracts later. But before going on to this correspondence, I feel it would be more in keeping to give you some idea of what the laboratories had already done at the time we sent in our first report to the department.

(*a*) Dr. F. C. Lea (Birmingham) has taken the keenest interest in the work *ab initio* and has had the co-operation of equally keen assistants in Messrs. W. Owen and Nai Yone. From a report made by our Research Visitor, Mr. D. B. Butler, we learn that "owing to the new University buildings at Edgbaston being largely occupied as a military hospital, the preliminary work and the preparation of the test pieces all had to be done at the old University premises, Edmund Street, and the test pieces carried to Edgbaston for testing." The work at this laboratory has been "done in duplicate, *i.e.*, the three aggregates . . . had been tested with the 'Cock' brand of cement, and also with that supplied by the Concrete Institute."

(*b*) Professor C. W. L. Alexander (Cork), assisted by Messrs. H. N. Walsh and W. Kingston, has also done very valuable work, and during the current year the activities of this laboratory have been continued; the work here has been sufficiently appreciated by the Research Department as to induce the latter to make arrangements for continuing investigations direct. At this laboratory a complete set of specimens has been made and tested. The College is also making, or has by this time made, additional specimens with a second kind of sand. The one month tests on the second series and the one and three month tests on the first series have been completed. Tests have been made not only to find the compressive strength, but also the tensile and shear strength and the elasticity of the concrete. A great deal of work on porosity has also been done, and as a result of the latter, the Science Committee asked the College to make additional tests to determine the best form of specimens.

(*c*) Professor P. F. Purcell (Dublin) did very energetic work during 1917 and furnished us with an ad interim report on the one month tests carried out on two separate sets of aggregates, the three months' tests being also at the time in hand. Mr. J. J. Carroll (who was responsible for the majority of those tests) accompanied his report by a diagram, and though I will not weary you with the details

of this report, it is of course filed for inspection amongst our papers. But in brief I would say, that the test specimens have been made with two mixed aggregates. All the necessary specimens, indicated in the Concrete Institute Programme, have been made, and in addition the compression tests at one month and at six months old have been completed. Special tests were made to ascertain the strength of concrete composed of aggregates having the volumetric proportions advocated by Fuller. Professor Purcell informed us that he had obtained the services of two first class men who would be ready to commence their activities in October this year, but of course the decision of the Advisory Council has upset our calculations.

(*d*) Principal J. C. M. Garnett (Manchester) was assisted by Mr. W. Leicester and later by Mr. H. Carrington. The results shown, upon the occasion of Mr. D. B. Butler's visit to this laboratory, were not such as to produce a favourable report; but I am enabled to say this, that Principal Garnett has been actively employed in getting matters into order for practical tests, including the fitting up of a special laboratory, and I should add that some tests have already been carried out.

(*e*) Principal B. Prentice (Salford) has done useful work. Reverting to Mr. D. B. Butler's report of his visit to this Laboratory, we learn that, with the assistance of Messrs. F. E. Drury and H. Wood, the preliminary work had been done and a series of test pieces made, first of all with Appley Bridge stone and Claremont sand, and a further series of tests were being made with the same aggregate, but with Mersey sand. The Laboratory is well equipped, and, to quote Mr. Butler, "Generally speaking, there was intense keenness shown in the work in this Laboratory, and the results should prove very valuable."

In all these cases it will be obvious that a further 12 months' work would have shown such an advance as would, I am convinced, have secured a renewal year by year of the grant originally sanctioned by the Advisory Council.

I hope I am not wearying you with my resumé of this research scheme, but I think, before concluding, it is well that I should indicate to you what has been the correspondence between the Research Department and ourselves.

After our Report for 1917 had been sent in to the Department (and it is only right to add that some of the

information which I have given to you was not available at that time for submission) that body took it into consideration, and subsequently we received a communication from it to the following effect, namely, that the Advisory Council decided that "they were unable to recommend the grant, as in their opinion the research should be suspended until more co-ordination and continuity of effort could be secured under adequate supervision." At the same time they forwarded a confidential report upon which their decision was arrived at, but I feel that as this report was forwarded as a confidential communication to lay merely before the President and Council, I am not at liberty to divulge its contents *in extenso*; you may take it from me, however, that whilst the Special Committee appointed by the Advisory Council considered that in general the expenditure incurred was legitimate, they adversely criticised the sum expended by Manchester for fitting up a special laboratory. But now I would add further that the Concrete Institute was so satisfied that the Advisory Council had not done justice to the work undertaken by this Institute, and the results obtained and obtainable, that it appointed a small Sub-Committee to consider a suitable reply, to be sent to the Council, of which I embody a copy :—

"Sir,

The Maintaining Body (the Concrete Institute) has had before it your letter of May 31st, 1918, informing it that the application for a grant in respect of the investigation into concrete aggregates has not been acceded to. I very much regret this, and in the belief that there has been some misunderstanding of the facts would (on behalf of the Maintaining Body) ask your Council to reconsider its decision, keeping in view the following aspects of the case :—

I. Amount of Grant.

I would point out that the amount of the grant asked for for the year 1918 (*i.e.*, £175) is very small in view of the importance of the research undertaken. The balance carried over from the grant for the financial year 1917, amounting to £767 4s. 8d., makes up the total of £942 4s. 8d.

II. Central Institute or Scattered Laboratories.

The relative advantages of these two possible methods of carrying out the research (*i.e.*, Central Institute or Scattered Laboratories) have been carefully weighed by the Maintaining Body before deciding upon

the method of decentralising, and it was felt strongly that the advantages lay with the latter method for the following reasons :—

(*a*) To carry out the work in a single Central Laboratory would involve the provision of a special full-time staff devoted entirely to this work, and this was felt to be impossible during the war. Whereas to utilise existing staffs for part of their time only made it possible to carry out the research during the war.

(*b*) The carriage of aggregates from different parts of the country to a Central Laboratory would throw unnecessary work upon the railways.

(*c*) A very important advantage of decentralising the research is that in this way a widespread interest in concrete research was more likely to be stimulated, each laboratory forming a nucleus for the growth of accurate knowledge and interest. The advantage of this is obvious, in view of the certainty of a wide development in the use of reinforced concrete in the future.

(*d*) The accumulation of information at local centres relative to materials in the neighbourhood is a point of great advantage.

(*e*) The educational value of decentralising the research was felt to be of great importance, as instead of a single staff in a single Central Institute becoming expert on questions relative to the use of concrete, the number of men who would acquire such knowledge and experience would be multiplied many times by utilising the different laboratories throughout the country. I believe that as a result of careful standardisation of the methods used the value of the research will be little, if at all, inferior to that which would result from operating with a single Central Laboratory.

rgency. Owing to the large amount of reconstruction work which will inevitably become necessary after the war, I believe that a most important function of the research is to obtain now, and have ready when the war ends, the information aimed at in the programme already

placed before you, and that to postpone the work would therefore detract greatly from its value to the nation.

IV. First Year's Work Preparatory.

Owing to the nature of the research the work of the first year was necessarily to a great extent preparatory, including the organisation, co-ordination of research, preparation of materials and plant, and of test blocks, which can only be broken after suitable intervals have elapsed for seasoning. I would wish to bring out strongly this latter point, *i.e.*, that owing to the necessity of seasoning specimens over long periods of time the very nature of the research precludes the possibility of quick results.

V. Work in Hand.

There is a large amount of work already partially completed and specimens moulded, but not ready for testing until seasoned for the requisite time; aggregates have been collected, but not analysed, and generally there is much work in an incomplete state which, it is thought, it would be a mistake to abandon. The work in hand, if stopped at once, would absorb the greater part of the £942 without producing useful results, because the specimens already prepared could not be tested.

VI. Co-operation of Geological Survey.

There appears to be some misunderstanding on this point, as we have a representative of the Geological Survey on the Maintaining Body and have arranged for its full co-operation in the work. Indeed, there is already a large amount of valuable information in our hands collected and specially tabulated by the Geological Survey. We have also arranged for the co-operation of the Geological Survey of Ireland, and it has appointed a representative on our Committee; so that we think the statement in your report on this matter is not quite in accord with the facts. We shall be pleased to place before you, if you so desire, the tabulated results above referred to, as prepared by the Geological Survey.

VII. Co-ordination.

In regard to co-ordination, the necessity for this was always kept in view. The programme was prepared in order to standardise the methods used. Special standard forms were prepared for tabulating and reporting the results.

With respect to visitors, it must be remembered that owing to the war the first year's work was delayed, and really pushed into the second year, and until actual

work was commenced there was no need for a visitor. As soon as testing work was begun we sent a specially appointed visitor to the laboratories. During the first year there were only two laboratories at work (Cork and Dublin), and one of these, *i.e.*, Cork, was under the supervision of Mr. H. C. Johnson, one of the two visitors appointed; the other laboratory, Dublin, was also visited. I would point out that two voluntary visitors were appointed in the first instance, but now one paid visitor in addition (Mr. D. B. Butler) has also been appointed, and he has recently made a round of inspection and reported to the Maintaining Body.

Military ce Act.

Although during war conditions we realise that all such research work must be adversely affected to some extent, we may say that we have no reason to anticipate serious difficulty arising from the operation of the new Military Service Act. We have made express inquiries from the co-operating laboratories as to the anticipated effect of this Act on the research. Out of eight such laboratories six will be unaffected, one will be 'not much affected,' and in one the research will be 'made difficult.'

In conclusion, the Maintaining Body hopes that your Council will reconsider its decision keeping the above points in view, and that it will feel itself thereby justified in authorising the small grant asked for."

You will doubtless agree with me that this was putting matters very fairly, but in spite of all, the Advisory Council, at a later date, informed us that it could not reconsider its decision to suspend the research, this decision being based upon the desire to await a time "until more co-ordination and continuity of effort can be secured under adequate supervision."

With regard to the list of aggregates that we have filed at the Concrete Institute, members could greatly assist by obtaining from the Secretary a list of aggregates in the neighbourhood of the site of any new buildings they are erecting, and by reporting on any of the materials after use.

The Standard Specification for Reinforced Concrete is now nearly ready for publication, and in reference to this I should like to call the attention of members to the generous action of Messrs. A. Alban H. Scott and Percival M. Fraser in placing at the disposal of the Concrete Institute

the copyright of their Standard Specification for Reinforced Concrete Work, with full permission for the Institute to make what use the latter deems essential in respect to this copyright. I feel that I cannot speak too highly of Messrs. Scott and Fraser's action in this respect, and I am sure all members will be at one with me in desiring to place on record our hearty vote of thanks to them at the first public meeting subsequent to receiving their letter stating the decision at which they had arrived.

The " Recommendations to Clerks of Works and others engaged in the execution of Reinforced Concrete Work " has been approved for publication, and is now passing through the Press.

The Sub-Committee appointed to deal with the use of high-tension steels in reinforced concrete has held several meetings, and is proceeding with the manufacture of beams and slabs for immediate testing purposes.

A Sub-Committee has been appointed to investigate the question of the use of reinforced concrete in shipping, consisting of representatives of the Admiralty, the Board of Trade, Lloyd's Register of Shipping, the Institution of Naval Architects, and the Concrete Institute. At the first meeting Sir Henry Tanner was elected Chairman, and a preliminary programme was drawn up as follows :—

(*a*) Different methods of construction adopted or under consideration.

(*b*) Special difficulties arising in this form of construction—

(i) Forms,
(ii) Aggregates,
(iii) Permeability,
(iv) Cracks arising from shrinkage and shear.

(*c*) Spacing of reinforcement with a view to preventing cracking.

(*d*) The possibilities of decreasing the weight of concrete.

(*e*) Waterproofing.

The question of the reconstruction of the building industry after the war, as dealt with in the Report of the Materials Committee of the Ministry of Reconstruction, is of great interest to us.

The Government proposes to appoint a post-war Priority Committee of Ministers to determine broad lines of policy with regard to priority, and also a Standing Council for consultation with and for securing the advice of representative trade bodies for furnishing the Cabinet Committee with considered counsel and assistance in the detailed execution of the policy determined upon.

The scheme suggested in the Report is an organisation which, acting in co-operation with the Standing Council, will secure (i) stimulation of production of all essential building materials, (ii) utilisation of available materials and labour without delay, (iii) direction of the building industry by the organisations directly concerned, and (iv) gradual relaxation of control and entire freedom from control at the earliest possible date. The scheme is as follows :—

The establishment of a Central Building Industries Committee to determine (on lines of policy laid down by the Standing Council) all matters connected with the production of materials and the allocation in the national interest of the building materials and resources of the country. For the purpose of administration, England and Wales will be divided into regional areas, nine in number, and for each of these areas a Regional Building Industries Committee will be established. The functions of these Committees will be to act under general directions of the Central Committee in (*a*) stimulating production within their area, and (*b*) the regulation and distribution of building materials. This will be done by means of the issue of building permits by the Regional Committees. The Central Committee will ration the Regional Committees with materials, and the Regional Committees, with these quantities of materials before them, will decide for how many of the applications for building licences before them the materials available will be adequate ; and if the materials are only sufficient for 50%, they will issue permits for only 50% of the buildings applied for. The procedure will be as follows :—

A building owner, desirous of building, will, in the usual pre-war manner, submit his drawings to the Local Authority ; the application for permission to build will be made to the Regional Committee, which will decide (after considering the nature of the building, the local circumstances, and as to the materials and labour available) whether the building permit shall be issued or not. Upon the grant of a permit no further priority of materials or

labour will be issued or required. The builder will be free to order the materials from the manufacturer or merchant as and when he chooses from the area allocated.

The only works to proceed without permits are, including works of repair, under £500 in value. This limit will be varied by the Central Committee as circumstances require.

There is no doubt that the people in this country are very anxious to obtain relief from the troublesome necessity of getting their permits, and every effort ought to be made to put on these Committees people whose interest should be to terminate the present control at the earliest possible moment.

There appears to be plenty of steel for constructional purposes, and the output of cement does not present any great difficulty; so that the building industry, in which we are interested, may look forward to a very busy time, if the existing high prices of labour and materials are brought down to a reasonable figure. The Report does not make any proposals with reference to the control of prices, nor does it suggest that manufacturers should sell otherwise than in the open market. If the works producing building materials are enabled to proceed to their full productive capacity as early as possible, and thus cheapen production directly and through the reduction of on-cost, and also if labour is forthcoming and will but increase its output, then the building industry will be re-established soon.

The question of finding work for the returned soldier is one of the most serious problems that will be within the purview of the Regional Committees, and in this connection the Cottage Building Scheme will be of great use as affording opportunities for employment when there is labour available; the Housing Scheme which the Government is subsidising will make a useful reservoir to be drawn on where employment is needed.

So much has been said about the housing problem that it is difficult to find any point not touched on, but I should like to suggest that the insulation of walls and ceilings to make warmer cottages is worthy of consideration; and if this is done the ventilation of the rooms must have careful attention, as the breathing power of brick walls and plaster ceilings is of considerable value in small rooms. For the finish of concrete floors in these houses the composition made with sawdust, cement, and magnesite is recommended, but I should like to point out the danger of having mag-

nesium sulphates near iron; there have been many cases where these floors have been used and the steel reinforcement has been seriously injured.

A series of experiments on solid floors for cottages is now being carried out by a Committee appointed by the Local Government Board at the Testing Station of the British Fire Prevention Committee. Up to the present two types of floors have been tested, and it will be interesting to hear the results. The object of the inquiry is to ascertain the most economical and efficient form of solid flooring as a substitute for timber construction.

I would just make a passing reference to our Library, of which we hope that more use will be made in the future. Our staff has been engaged in arranging and cataloguing the books, and those members who may have occasion to use the Library will find that the books are readily available for reference.

In connection with demobilisation, it might be of assistance to some of our members with the Forces if we took action, as some of the other Technical Societies have done, to obtain the early return of our members as pivotal men. For those who do not get early release it would be useful if they could take up some study in connection with the occupation they propose resuming on their return to civil life. Mr. William Dunn has offered, as Lecturer and Instructor, to take charge, for the study of reinforced concrete, of a class of young men released from service.

We are entering on a new era, when reconstruction is at work everywhere. Let us do our part as an Institute with a great future, and make use of the many opportunities of advancing the knowledge and influence of our members, that they may reap the reward due to patient industry and merit.

The War Office is offering every encouragement for these studies, and I think that this is a subject that ought to occupy the attention of the Concrete Institute. It is proposed to establish an entrance examination as soon as possible after the war, and I give the syllabus to guide those who wish to study. It would help young men, if it is made known, that the fact of having followed such a course of study would be accepted as a qualification for admission to the Concrete Institute; it would give those who thought of taking up work in connection with the industry with which our Institute is in sympathy an additional object to work for.

SYLLABUS OF THE EXAMINATION.

Part I.—(A) Compulsory Subjects.

1. Principles of Statics and Theory of Structures.

Forces acting on a rigid body; composition and resolution of forces; couples; moments of forces; conditions of equilibrium, with application to loaded structures. Graphical and analytical treatment of the foregoing. Centre of gravity; specific gravity.

Graphic and analytic methods for the calculation of bending moments, shearing forces, and the stresses in individual members of framed structures loaded at the joints; reciprocal diagrams; incomplete frames and redundant members; buckling of struts; effect of different end fastenings on their resistance; combined stresses; section modulus; methods of dealing with statically indeterminate problems, as beams supported at three points, etc.; travelling loads; rigid and hinged arches; stresses due to weight of structures; theory of earth pressure and of foundations; stability of masonry and brickwork structures.

2. Strength and Elasticity of Materials.

Physical properties and elastic constants of cast iron, wrought iron, steel, timber, stone, concrete, cement, and other materials; relation of stress and strain; limit of elasticity; yield-point; Young's modulus, coefficient of rigidity; extension and lateral contraction; resistance within the elastic limit in tension, compression, shear, and torsion; strength and deflection in simple cases of bending; beams of uniform resistance; reinforced concrete beams.

Ultimate strength with different modes of loading; plasticity and permanent set; working stress; phenomena in an ordinary tensile test; stress-strain diagrams; suddenly applied and impulsive loads; resilience; fatigue of metals; effects of hardening, tempering, and annealing.

Forms and arrangements of testing machines for tension, compression, torsion, and bending tests; instruments for measuring extension, compression, and twist; forms of test-pieces and arrangements for holding them; methods of ordinary commercial testing; percentage of elongation and contraction of area; test conditions in specifications for the principal materials of construction.

PART I.—(B) SELECTIVE SUBJECTS.

Two of the following subjects must be taken in addition to the compulsory subjects :—

3. CHEMISTRY.

Constitution of matter; chemical elements; Dalton's atomic theory; Newland's law of octaves; Mendeleeff's law of periodicity; modes of chemical action; atomicity; analysis and synthesis; composition of materials employed in structural engineering.

4. PHYSICS. (Note.—A candidate taking this subject must be prepared to answer questions in three of the five sections.)

Sound.—Nature of sound; pitch, intensity, and timbre; transmitting media; velocity of sound; sound waves; vibrating strings, plates, and membranes; resonance; interference; reflection and absorption of sound.

Light.—Theories of light; transmitting medium; velocity of light; solar spectrum; laws of reflection; photometry; candle-power; candle-feet; absorption of light; colour; polarized light; action of lenses; telescope and microscope.

Heat.—Sensible and latent heat; thermometers; pyrometers; effect of change of temperature in solids, liquids, and gases; transfer of heat; radiation; conduction and convection; relative conductivity; thermal units; Joule's equivalent; thermal capacity; specific heat; combustion.

Magnetism.—Magnets; magnetic phenomena; magnetic field; polarity; the mariner's compass; magnetic meridian; deviation and declination of the compass; inclination or dip; induction; galvanometers.

Electricity.—Static and voltaic electricity; induction; conductors; electro-negative and electro-positive elements; electrolysis; lightning; system of electrical transmission; electrical units; measurement of electrical work; Ohm's law; principles of arc and incandescent lighting.

5. HYDRAULICS.

Pressure on surfaces; centre of pressure; strength and stability of structures supporting water pressure; laws of fluid friction; impact of water on surfaces; storage of water and construction of reservoirs.

6. Geology.

Classification of rocks; succession of strata in aqueous formations; explanation of geological terms; glacial drift; conditions of deposition in fresh and sea water; denudation; disintegration and chemical decomposition of rocks; method of dealing with bad ground for engineering works.

7. Geodesy.

The theory, structure, and adjustment of the principal surveying and levelling instruments, and the principles of their employment under various conditions; land surveying; contouring; levelling and use of theodolite.

Part II.—Technical.

Subject 8 must be taken by all candidates, and at least one other subject.

8. Structural Engineering (Generally).

Materials of construction; loads—dead loads (distributed and concentrated), live loads (rolling and suddenly applied); bending moments; resistance moments; stresses and strains; shear stresses; deflection; secondary stresses, fatigue of metals; safety factors; wind pressures; standard sections of rolled steel; properties of sections; girders—rolled sections (simple and compound), plate web and lattice web, trussed frame; pillars, columns, stanchions, piers and struts generally; eccentric loading; fixity of ends; roofs—symmetrical and unsymmetrical trusses; connection of parts; bridges—girder, suspension, cantilever; arches—elastic rib, rigid and braced, two and three pivoted; methods of erection; testing and inspecting materials of construction; effect of workshop processes on steel; mass retaining walls and their stability against water pressure and earth pressure; pressures in silos, bins, and hoppers.

9 Reinforced Concrete Construction.

General principles; advantages and disadvantages of reinforced concrete; materials of construction and their testing; nature and properties of materials for concrete; mixing concrete by hand and machine; effect of frost and precautions to obviate damage; laying concrete; testing

actual concrete used; testing completed structures; failures and causes; comparison of cost with other methods of construction; fire-resisting properties; causes affecting expansion and contraction; surface finish; durability and maintenance; form work (centering, shuttering, strutting, moulds, etc.), precautions in fixing, order and periods of removal.

Routine of designing; arrangement of roof and floor slabs, cross beams, main beams, and pillars; loads on floors; calculation of reinforcement for various parts; loads on foundations; rough estimates of cost; rules and regulations.

10. Steel Frame Construction.

Order of procedure in designing; external forces, wind, snow, etc.; arrangement of roofs; loads on floors; arrangements of main and cross girders and stanchions; caps and base plates; grillages; junctions; erection; brick and stone panels and casings; protection against fire; painting; rough estimates of cost; rules and regulations.

Candidates desirous of being examined in Masonry, Bridgework, or any other branch of Structural Engineering not specified above may be so examined subject to the approval of the Examination Board and upon notifying the Secretary at least six weeks beforehand.

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Ferro-Concrete Ships.

By J. S. E. DE VESIAN, M.I.Mech.E.

The concrete ship has arrived and has undoubtedly come to stay in spite of all the cheap witticisms and gloomy prognostications. Every new idea is greeted in the same manner—railways, steamships, motor cars, the use of electric power, have been in turn greeted with a chorus of condemnation; to be unaccustomed is in fact to be criminal.

The latest type of naval vessel, the submarine, is no doubt largely responsible for the rapid advent of the concrete ship; if tonnage had not been required so badly it is possible the Admiralty would not have contemplated a programme of ferro-concrete ship construction, which has given an opportunity to designers and builders to gain experience and thus place this new industry firmly on its feet.

Much has been written on the subject of concrete ships during the last twelve months and a dozen or so vessels of 1,000 tons have been launched. Up to this time attempts had been made with varying success to produce small boats or lighters and barges, but no serious attempt to construct a sea-going vessel had been made. It is not proposed in this paper to deal with the history before the war or to the general principles of ferro-concrete as applied to ships, but to endeavour to show the evolution of methods of construc-

tion and in particular that method known as monolithic in contradistinction to the unit systems. The boldest experiment in this direction was carried out in the United States in the building of a vessel called the "Faith," which, like her prototype in steel ship construction the "Great Eastern," has been a success, but was before her time. The details and performance of this ship have been widely published and the experience gained of great value.

All ferro-concrete ships built up to now have been heavier than steel ships of equal dimensions, and this fact has been used as the great argument against their successful competition with steel vessels; but it must not be forgotten that the cubic capacity is greater and therefore for light cargoes, such as fruit, cotton, jute, Eastern goods, wine, etc., they can carry larger cargoes than the steel ship, and if used in such trades, which represent a very important part of our imports, the concrete ship would prove to be economical and advantageous. To-day valuable fruit cargoes are carried on deck owing to lack of capacity below, and heavy losses are incurred through damage by sea water which would be avoided if carried in a ferro-concrete vessel.

At the outset it was apparent that to evolve a satisfactory design for the vessels the collaboration of experienced naval architects with ferro-concrete engineers was essential. The author's firm, L. G. Mouchel and Partners, therefore entered into an agreement with the Ferro-Concrete Ship Construction Co. (a firm in which Messrs. Vickers, Ltd., were largely interested) for the latter to act as naval architects, and upon the data which they furnished the details of the ferro-concrete were worked out.

The design of steel ships is largely empirical and this is so because while it may be easy to calculate the stresses to which a vessel will be subjected in still water it becomes well nigh impossible to compute accurately the effects of the torsional and racking strains, etc., which a vessel suffers in a sea way. Various rules have been laid down by the classification societies which embody the result of long experience gained through the classification and survey of ships for many years past, and in studying the design of concrete ships it was felt that one could only "translate" into ferro-concrete the strains which it had been customary to work to in connection with steel ships.

The rules of the classification societies of Lloyds

Register of Foreign Shipping and the British Corporation for the Survey of Shipping provide for vessels such as now under construction being designed to meet certain conditions. The first condition is that the vessel is assumed to be suspended between two wave crests, the length between the crests being equal to the length of the ship between perpendiculars and the depth of the wave being taken at 1/20th of the ship. This condition is termed sagging. The alternative condition, namely, hogging, takes place when the ship is assumed to be supported amidships on a crest of the same theoretical wave, and obviously in this case the ship as a whole acts as a cantilever. It will be obvious that when a ship is in a sea way the deck and bottom of the vessel will be alternatively in tension and compression, and there will be other strains which have to be allowed for in the design of the ferro-concrete work. It naturally follows that practical considerations govern the design to a certain extent and this applies both to steel vessels and ferro-concrete vessels. In the former, for practical reasons, the structural steel work is not used to the most economical advantage in vessels of small tonnage, and the same reason applies to the concrete used in the ferro-concrete vessels. While it may be possible from a theoretical point of view to have a thickness of say two inches of concrete, such a thickness would not be recommended by one having practical knowledge of the difficulties involved in the proper manufacture of a watertight concrete of this thickness.

The remarks in this paper as to vessels now under construction relate to the barges and tugs ordered towards the end of 1917 by the Deputy Controller of Auxiliary Shipbuilding, which department is now under the control of the Ministry of Shipping, and also in connection with the design and construction of some steamers which the Ferro-Concrete Ship Construction Co. decided to lay down as an experiment prior to the commencement of the Government programme.

The first of these steamships, ss. "Armistice," left Barrow on January 7th of this year on a voyage to Londonderry, where she was loaded with 1,000 tons of oats in bulk, and sailed from there to London. Very severe weather indeed was encountered, many steel ships put in damaged, but the vessel successfully withstood the trial and brought her cargo in perfect condition to London and sustained no damage whatever herself.

As regards the barges and tugs building for the Government, the leading dimensions of these are as follows:—

BARGES.

Length between perpendiculars	...	180	ft.	0	in.
Breadth	...	...	...	...	31	,,	6	,,
Depth	...	...	...	...	19	,,	6	,,
Draft loaded	...	...	...	...	8	,,	0	,,

TUGS.

Length between perpendiculars	...	125	ft.	0	in.
Length overall	...	...	...	132	,,	9	,,
Breadth on 12ft. 0in. water line	...	27	,,	6	,,
Depth	...	...	...	...	14	,,	9	,,
Draft—mean	...	...	...	...	12	,,	0	,,

The cost of the first vessels from each yard has naturally been high, in fact considerably higher than the cost of a similar vessel in steel. This is largely due to the question of timber moulds. Subsequent vessels from the same moulds have cost considerably less, and as duplication is increased the cost will come down more and more. The difficulty of the labour market and of obtaining materials during the period in which the vessels were under construction has prevented rapid completion and this again has prevented the cost from being as low as it will be subsequently.

The first contracts let by the Admiralty were for some 200 (odd) vessels of two types—1,000 tons d.w. dumb barges and for steam tugs of 750 h.p. These orders were entrusted to various firms, some established shipbuilding companies, and others established for the purpose of their construction. Various designs were employed, some firms working on what is known as the unit system, pre-casting separate portions of the vessel and building these portions into the fabric; and others on the monolithic system, making moulds and working the concrete and steel *in situ*. The former method was adopted by Messrs. Concrete Seacraft, Ltd., at Fiddlers Ferry; Messrs. Hughes and Stirling, at Preston; Messrs. Blacketts Concrete Ship Co., at Darlington; Messrs. Stuarts Concrete Ship Co., on the Thames; Messrs. Christiani and Nielsen, at Tilbury; and the latter method was adopted by Messrs. Hill, Richards and Co., of Poole, who designed the dumb barges on a special method with double skins. Messrs. The Aberdeen Concrete Shipbuilding Co., The Scottish Concrete Ship Co., Amble Ferro-Concrete

Co., Gloucester Ferro-Concrete Shipbuilding Co., British Construction Co., Queenborough Shipbuilding Co., J. and R. Thompson, Ltd., of Warrenpoint, in Ireland, and the Ferro-Concrete Ship Construction Co. adopted the single skin monolithic type from the designs of the author's firm.

Six months before the order for these dumb barges had been given by the Admiralty, the Inland Water Transport Department had entrusted Messrs. Stewart and Partners with the construction of two 500 ton d.w. barges, and these vessels were constructed by them at Brentford, and are now in service.

The first of the 1,000 ton barges to be launched was from the yard of Messrs. Hill, Richards and Co., at Poole, August, 1918. This vessel was rapidly followed by launches from Barrow-in-Furness and Barnstaple yards on the 21st September. Since that time nine further vessels have been launched, and two from the yard at Poole, the double skin design being discarded now in favour of the single skin monolithic type at that yard.

While the double skinned boats carried only 780 tons, the first 1,000 ton boat from Barrow was capable of carrying 950 tons, and subsequent vessels rather more. These dumb barges have been in service carrying goods between Southampton and Havre on Government service, and have received consistently satisfactory reports from the officials deputed to report on them.

The concrete vessel from which the most useful data will undoubtedly be obtained for guidance in the design of future vessels is the ss. "Armistice," launched at Barrow.

The leading dimensions of the boat are given below as well as the corresponding particulars for a steel vessel of the same d.w. carrying capacity.

	Concrete.	Steel.
Length between perpendiculars	205 ft. 0 in.	188 ft. 0 in.
Breadth moulded	32 ,, 0 ,,	30 ,, 3 ,,
Depth moulded	19 ,, 6 ,,	17 ,, 3 ,,
Draft when loaded	15 ,, 6 ,,	14 ,, 6 ,,
Dead weight	1,150 tons	1,150 tons
Displacement	2,350 ,,	1,800 ,,
Indicated horse-power (about)	400 (about)	400
Speed ... ... ,,	$7\frac{3}{4}$ knots ,,	$7\frac{3}{4}$ knots

The lantern slide indicates the general arrangement of the vessel, which follows more or less the lines of the usual

tramp steamer. The quantity of concrete employed in the vessel was 500 cubic yards and the total weight of steel about 190 tons. The steel is about 42½ per cent. of the weight that would have been required for a steel ship. It was not thought advisable to reduce the steel to a minimum for the first experimental vessels, but the results obtained have been so highly satisfactory that further consideration can be given to the design with a view to seeing if further possible reductions and simplifications can be made.

The next slides illustrate the vessel in course of construction. Owing to the greater displacement of the concrete vessel the fittings and equipment generally were required by the registration societies to be of a somewhat heavier type, and also, naturally, many of the castings had to be specially designed to permit of their attachment to the concrete work, and this question is somewhat more intricate than in the case of steel vessels. After the first voyages the hull was in a perfectly satisfactory condition.

Materials. The author does not propose to deal exhaustively with the physical qualities of concrete materials, members being well acquainted with the requirements to produce the strongest and most impermeable concrete which in ships do not vary from the best practice in ordinary land structures. The proportions of voids in both aggregate and sand must be carefully ascertained and the grading and quantities of the components of the mixture proportioned accordingly, care being taken to ensure an excess of cement paste over that necessary to fill the voids in the sand, and an excess of mortar over that necessary to fill the voids in the aggregate. Owing to the scantlings in a ship being reduced to a minimum to save weight the aggregate must be somewhat finer, *i.e.*, broken to a smaller gauge than is usual with buildings and engineering structures, and it follows therefore that the voids will be greater.

The author's firm eventually adopted the following proportions for the concrete:—

Aggregate broken to pass ½in. gauge, *i.e.*, ⅜in. to ¼in. free from smaller particles and dust	27 cub. feet.
Sand ⅜in. to dust	13½ ,,
Cement	8½ cwts.

These proportions will apply so long as the percentage of voids in the aggregate does not exceed 50 per cent.

When the voids are greater a corresponding extra quantity of sand and cement must be added.

The Admiralty specification calls for permeability tests. Slabs of concrete 9 inches square and 2 inches thick have to be cast between moulds and sent to Messrs. Kirkaldy and Son for testing. Eight days after casting the slabs are placed under a pressure of 30lbs. per square inch for four days, at the end of which the upper surface of the slabs should show no signs of dampness. These tests have been carried out during the actual construction of the work with satisfactory results.

As regards the shuttering for monolithic vessels, this was designed substantially on the usual lines, but special arrangements were made to permit of the removal of the shuttering when the concrete had set, and its rapid re-erection for succeeding vessels.

With a view to economy in the cost of shuttering work and speed of erection it was decided to keep the lines of the ship as straight as possible, and to this end, in the case of the Admiralty dumb barges, a simple midship section was adopted, with straight sides and bottoms and a very small radius at the bilge. For half the length of the vessels amidships the aforementioned section obtained. The bow and stern had of course to be shaped, but here straight line sections were maintained as far as possible.

The author, however, is of opinion that from the experience so far gained in the erection of the shuttering for vessels built it would be a comparatively simple matter to arrange the shuttering for a vessel built with the usual curved lines.

At the commencement of the programme, when timber was very difficult to obtain, a system of steel shuttering was initiated, there being a large amount of steel sheets available, and this system has proved quite satisfactory. The steel plates were built up in panels stiffened with timber and bolted together, and capable of being re-used a very large number of times. This question has received considerable attention, and a new form of shuttering has been evolved by Mr. F. Brazendale and patented by him, which the author considers a decided advance. The method is described as follows:—

When shuttering is constructed in panels the whole height of the vessel, these panels are of a convenient

width to take standard sheet iron. The frames supporting the iron sheeting are of light section steel work bolted together to form a continuous mould and capable of being moved up to and away from the steel skeleton of the vessel. When the moulds are made of timber and the steel work afterwards assembled great difficulty is experienced in setting the steel, and with this method it is proposed to erect the floors and frames as complete skeletons, the component parts being wired or welded to one another so as to form rigid members, the frames being set up and the lines faired, the steel work of the skin of the ship being complete without any shuttering to interfere with the work, so that it may be handled from both sides, which is impossible when a wood mould is first erected. After the steel skeleton is completed the panels of shuttering are moved up into position the correct distance away from the skeleton and bolted together to form a continuous mould, the internal shuttering being erected lift by lift as usual with timber or sheet iron panels.

With this method, therefore, the shuttering need only be in position for just so much time as is necessary for getting the concrete in, and can be moved away directly the concrete has set sufficiently to support itself, and taken to a fresh slip and used again.

If this method of shuttering is used in conjunction with an improved method of making the bottom and floors, a great saving will be effected in the time of construction and cost.

In making the bottom a flat sheeting of timber in panels is provided, the bottom steel being placed in position arranged in such a way, as to enable it to be efficiently joined to the floors after the bottom has set. At present, assembling all the steel work *in situ* breaks the bottom up into small panels between the shuttering of the floors and makes concreting difficult and slow. With this method a clear flat run of floor can be made just like the floor of an ordinary building, and the bottom concrete being set, the floors with part of the frames which composes the bottom of the ship can be lifted bodily into position as a rigid skeleton. The shuttering for these floors can then be easily placed in position on the finished concrete floor and the floors concreted easily and without danger of dirt or hollow places being left owing to the difficulty of getting the concrete in

if it is attempted to concrete the whole of this part of the structure at once.

The following slides illustrate the proposed methods.

The author confidently anticipates that vessels built according to these improved methods will be constructed infinitely quicker and far cheaper than will be possible with a similar size steel vessel.

In a paper read by Mr. T. J. Gueritte before the North-East Coast Institution of Engineers and Shipbuilders in March of last year he gave a number of interesting figures in connection with the weight of ferro-concrete vessels in comparison with steel, and he has been good enough to lend the author lantern slides illustrating these comparisons.

Table 1 illustrates the main characteristics of the vessels. From these figures a diagram sheet was prepared representing the disadvantage in the matter of weight of ferro-concrete vessels of small tonnage, which becomes less marked as the carrying capacity of the vessel increases. This is chiefly due, as Mr. Gueritte says, to the thickness of the concrete skin necessary for practical considerations which does not need to be increased in proportion with the tonnage curve.

Diagram 2 and Table 3 show the variation of the extra displacement of ferro-concrete ships, and that for a 1,000 ton d.w. steamer the total displacement of the ferro-concrete vessel is greater by as much as 39%; for 2,000 tons d.w. the excess is only 30%; for 4,000 tons the excess is only 18%; and for 6,000 tons d.w. the excess is only 15%. These figures the author considers from his experience to be very fairly accurate, and, if anything, rather too high. But as previously stated, it must always be kept in mind that the greater cubic contents of a ferro-concrete ship compared with an equal d.w. carrying capacity exceed that of steel vessels and for all bulk cargoes the concrete ship will have the advantage over its steel rival.

Hysteresis.

The author discovered that the use of ordinary mild steel bars with an ultimate tensile strength, say, at rupture of about 63,000lbs. and the yield point corresponding to about 32,000lbs. per square inch, accounts for a large part of the slight sagging which is noticed in reinforced concrete structures after they have been loaded or stressed for the first time. This sagging does not increase by subsequent stressing, and in order to obviate the appearance of such

sagging, engineers or architects are in the habit of specifying that the beams should be moulded with a slight camber. The author considers that this initial sagging is due mostly to the phenomenon of initial permanent set, or "hysteresis," to borrow the term used by electricians to denote a similar phenomenon observed in their sphere of knowledge; and it is also exhibited by ordinary steel structures when stressed for the first time. In the case of reinforced concrete, however, this initial set causes initial stresses in the surrounding concrete, and although less important in the case of ordinary building construction if proper factors of safety are allowed, in structures like ships where alternating stresses occur through hogging and sagging, the initial permanent set in the steel produces a somewhat unelastic state in the structure which is detrimental and materially increases the tendency of cracking of the concrete, which for obvious reasons must be avoided in ships.

The author's firm therefore decided to adopt a form of bar of which they had had previous satisfactory experience. These bars are made from ordinary mild steel and are more or less triangular in section with rounded corners. They are subjected to a special process of twisting, the effect of which is to produce in the bar that initial permanent set which would take place in a plain bar when first loaded. This twisting has also the effect of producing an efficient continuous bond and increases the elastic limit with a proportionately less elongation under calculated stresses.

These bars were used in the construction of ss. "Armistice," which on her first voyage from the North of Ireland to the Thames experienced extremely heavy weather, and her satisfactory performance has confirmed the author in the correctness of his view.

Previous mention has been made of a method of construction called the "unit" method, whereby the ships are built of pre-cast sections. It is very difficult for the author to express any views on the matter, as only one vessel of the Admiralty programme is at the present time afloat which has been carried out on this method of construction. From the author's experience generally of ferro-concrete work he doubts the expediency of attempting to build sea-going ships in this manner. Nothing is to be gained in speed of construction or economy of cost judging by the results achieved, and it remains to be seen whether they

will stand the severe punishment of a heavy sea as well as the ordinary type of ferro-concrete structure, although it is claimed that this method will produce small vessels more nearly approximating with similar steel ships in weight. But this result is obtained by reducing the thickness of the shell to a minimum, and the author considers that this is undesirable from a practical point of view, as a severe local blow or pressure on such thin concrete slabs has been shown to be rather dangerous.

Load lines approximate to calculated draught to about $\frac{1}{8}$in. tarring.

Slides. Launching stress diagrams.

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The Design of Steel Structures.

By ALBERT S. SPENCER.

Introduction.

The design of Steel Structures is a task very often undertaken without a reasonably sufficient knowledge of the principles involved. A widespread distribution of pocket books containing data and tables, provided primarily as time-savers, has enabled the recipients to utilise a limited knowledge of the theory of structures without, unfortunately, exercising a rational limit to its application; and whilst there is in existence authoritative control over misdirected effort where such endangers human life, there is no such control—except in competitive designing—over the waste material and effort expended in the manufacture of structures the design of which is inefficient. Hence it is very advisable that purchasers should take every precaution to secure expert service to meet their needs, and to remember that what at first sight appears to be cheap may ultimately prove costly.

The principal object to be borne in mind by the structural designer—ignoring artistic and utilitarian requirements—is to evolve a structure which necessitates in its construction a minimum amount and cost of materials, the

latter being distributed so that the structure will remain stable under the influence of the applied forces. This no doubt is a very elementary statement, yet nevertheless the saving that could be legitimately made in many designs by a more rigid attention to this fact, if a test be made, would amply repay the designer for his trouble. The economy is particularly marked where superfluous material is accumulated, as in the case of a multiple-storied building or in a bridge. In such a building any undue excess of material in the upper stories has to be supported by the lower stories, and ultimately by the foundations. In the case of a bridge the excess load acts as a force-moment, and where the span is only limited by the capacity of the constructive material this force-moment may have a serious effect in limiting the span.

The Theory of Structures.

The Theory of Structures embraces the application of mechanical principles to determine the stability and strength of structural units and of the units acting as a complete structure. These principles may be applied mathematically or graphically. The mathematical method is generally the simplest when the structure is rectangular in outline and when the external forces are normal to the exposed surface of the structure, whilst the graphical method is the simplest for structures having an angular exterior outline or when the external forces are angular to the structure. The principal points to be considered are :—

(1) So to arrange the outlines of the structure as to reduce its resistance to wind pressure to a minimum and at the same time limit the force-moment of the wind.

(2) The superimposed loads, or applied loads, should be kept down to the minimum consistent with safety.

(3) To examine the structure as to its stability and to endeavour to eliminate any possibility of distortion or displacement.

(4) To calculate the magnitude and nature of the stresses in the various units.

(5) To determine the sizes of the units so that each will safely resist the greatest stress that can possibly be set up.

(6) Where force-moments exist, to distribute the material in any unit so as to create the maximum

economic resistance moment, and also by introducing where possible such units as will enable the whole structure to have the maximum resistance moment.

(7) To take advantage of the variable unit resistance of the constructive materials.

(8) To select such sections and materials as are readily obtainable and are economical in cost.

(9) To arrange the members and the connections in such a way as to allow the direction and centre of action of the resistance force to coincide with that of the applied force.

External Forces.—The first step towards the achievement of efficiency in structural design, namely, to limit the external forces, can perhaps be best illustrated by a consideration of the outlines of a motor-car specifically designed for speed. The outlines of the car body will be such as to offer the minimum of resistance to wind force, or rather what is equivalent to wind force as regards effect, the result of which is to economise the power required to propel the car at any given speed.

A similar economy is obtained in a building (except that the saving is in the resistance necessary to maintain equilibrium and stability in lieu of power to propel) by the adoption of a low type of roof in preference to a high type —that is, by the use of a flat roof instead of a ridge roof, particularly if of large span. The economy is more apparent if it is realised that the extra wind force acting on the ridge roof has not only to be resisted by the framework of the roof itself, but also by the superstructure and the foundations.

A very economical and serviceable type of roof which was recently provisionally patented is a combination of the flat and ridge types, in which the ridged portion or portions are limited to the amount necessary for the natural lighting of the interior of the building. By the adoption of the suspension principle in the arrangement of the framework this special type of roof has many advantages where very large areas are required to be roofed, particularly if the supporting stanchions are to be kept to a minimum in number so as to not interfere unduly with the manufacturing process.

Force-Moments.—Reverting to the example comparing a flat type roof with a ridge roof as regards the comparative resistance to wind force, the centre of action of the wind force acting on the flat type roof is much nearer the ground than is that for the ridge roof; consequently, whether or not the ground level is coincident with the fulcrum round which the wind force acts, the moment of the wind force is certain to be reduced thereby, and as a reduction in the external force-moment leads to a corresponding reduction in the required resistance-moment of the building, there is in consequence a saving in the material required to give the necessary stability. The popular designation of a structure in which the force-moment is high is that it is "top-heavy." The frequent use of this term, even by a layman, proves instinctive aversion to the uneconomic effect of excessive external force-moment.

Superimposed Loads.—The advisability of adopting a minimum safe allowance for superimposed loads is so apparent that on first thoughts it appears inadvisable to enlarge upon such a simple matter. Yet by a too rigid attitude in the use of conventional allowances, or perhaps more particularly as the result of compulsory adherence to bye-laws, we are often reluctantly compelled to misuse our constructive materials, and thus violate one of the principles of the theory of structures. Take, for example, a large departmental store in a small township. The aggregate floor area may be such that the total load allowance for the human factor may considerably exceed the whole of the population, or, alternatively the total number of people who can possibly be expected to assemble in the building; nevertheless, no relaxation is permitted. Of course, it is admitted that during the past few years some authorities have permitted a certain reduction of load on certain portions of a multiple-storied building; but this permission is based upon the fact that only a portion of the floors may be subjected simultaneously to the maximum load, and not to the anomaly referred to. Under the present restrictions, however, advantage may be gained by calculating all loads on the lean side rather than on the full side, a procedure always followed by competitive designers who wish to survive as such.

Stability.—Although there are many excellent treatises which deal with the theory of structures, too much attention is given to the application of the theory to the stability of

structural units without sufficient consideration being given to the stability of the whole structure. A similar deficiency is noticeable in the treatment of this subject at our Technical Colleges. The result of this is discernible in present-day drawing-office practice, where many designers completely ignore the necessity for such stability calculations. There are many steel-framed buildings, and in fact buildings constructed of other materials, existent in this country which would not remain stable if exposed to the external forces which they are presumably expected to resist. Many units of a structure are habitually designed to resist a horizontal wind force of 40lbs. per sq. ft. and yet in the same structure units are permitted which would not resist one-quarter of this amount, nor would the structure itself. The reason they remain stable is in all probability due to the overestimation of the effect of wind pressure, and rather than have such inconsistency it is advisable to make a more conservative but consistent allowance. How many authors, for instance, deal with the design of foundations suitable for open sheds? Yet the stability of the shed depends upon its being provided with proper foundations. It is admittedly a difficult question to tackle, particularly to be able to square the result of applied theory with present practice, yet that is no reason why the question should not be rationally dealt with.

Calculation of Stresses. — The procedure generally adopted for the graphical determination of stresses is as follows :—

(1) Draw a line diagram of the triangulated framework to a suitable scale representing lines drawn through the centres of gravity of the various members.

(2) Calculate the amounts of the applied forces.

(3) Indicate the position, direction and amount of each force by means of an arrow. Note that these forces must only be applied at the intersection of the web members with the booms.

(4) Number the line diagram, allotting one number to each space between any two external forces, and also one to each internal space. The numbers should start, say, at the left-hand side, and progress in numerical order round the external forces, reactions and internal spaces. Set out the polygon of external forces to a suitable scale, beginning

with Force 1, and so on in numerical order, noting that each line representing any force must be set off in the direction in which the force acts.

(5) Before the polygon of external forces can be completed it is necessary to determine the amount and direction of each reaction. This problem may be solved graphically by constructing a polar diagram and a funicular polygon or (and this is often the quickest method) by the method of moments.

(6) The location of the reaction point enables the polygon of external forces to be completed, and the stress diagram can then be drawn, commencing at the point where the number of the unknown forces does not exceed two; then follow the numbers in numerical order. The proof of the correctness of the diagrams is in the closing of the last line.

(7) The amount of stress in any member may be scaled from the diagram, and the nature of the stress may be found as follows :—

(*a*) In numerical order, read off from the line diagram round the joint considered the number on each side of the member in question.

(*b*) Put an arrow on the corresponding line in the stress diagram, from 1 to 2 and so on.

(*c*) Transfer this direction to the member in the line diagram, then, if the arrow points towards the joint the member is in compression, and if away from the joint it is in tension. Note that the arrow on the line diagram only refers to the joint round which the numbers were taken.

When the mathematical method for the calculation of stresses is chosen the procedure is as follows :—

(1) When both bearings of the structure are equally fixed or equally free and the loading is symmetrical the direction of each reaction is the same and the reactions are parallel to the forces which produce them. The amount of load transmitted to each bearing is inversely proportional to the distance of the bearings from the point of intersection of the resultant of the external forces with a horizontal

line drawn through the reaction points or bearings; therefore calculate the aggregate external force-moment for the forces round one of the reactions and divide by the distance between the reactions to determine the force acting at the opposite reaction to the one taken as the fulcrum. The reaction force at the fulcrum will be the difference between the external forces and that of the known reaction force, since the total negative force must (to preserve equilibrium) equal the total positive force.

(2) When one bearing is fixed and the other free the reaction forces are calculated as in 1, except that the whole of the external horizontal forces are resisted at the fixed bearing.

(3) The difference between the positive moments and the negative moments is termed the bending moment, the value of which is variable from point to point since the cause is variable, and can be calculated by the method of moments. This bending moment must (to preserve equilibrium) be opposed by an equivalent resistance moment which is exerted by the material of which the beam is composed.

(4) As the result of positive and negative forces acting on the structure vertical shear forces are set up, the amount of which is the difference between the negative force and the positive force or forces situated between the vertical plane considered and the reaction where the negative force operates.

(5) Owing to the fact that the bending moment often varies in intensity along the beam, a horizontal shear force is created, and the amount of shear stress on any horizontal plane equals the increment of bending stress on that plane.

Determination of Sections. — The proportions and properties of the various units must be such that the material is only stressed within safe limits. The proportioning of parts subjected to simple stresses is very elementary and need not be considered here, but some remarks may be made with regard to where compound stresses exist in a unit, such as occurs, for instance, in struts. Units subject to bending stresses should have a modulus of section as large

as possible relative to the area, and the resistance arm should be sufficiently large to reduce deflection to within safe limits. Struts, particularly if of great length relative to width, and consequently subject to flexural stresses in addition to compressive stress, should have the radius of gyration as large as possible relative to the area. Where sudden changes of stress occur the material should not be varied in the same degree, particularly if the material is of a granular nature, and for the same reason; also in cases where the nature of the stress varies intermittently a higher margin of safety should be allowed.

Resistance Moments.—Where structural members are subject to flexural stresses economy may be obtained by distributing the material so as to produce the maximum modulus of section or radius of gyration (according to the utility of the member) relative to a given area. This economy is widely recognised; but taking, for example, the list of standard joist sections, it can be easily demonstrated that the compilers have not taken full advantage of this principle of economy in the use of materials. Now the basis of measurement of the comparative efficiency should take into consideration the area—or weight—resistant lever arm or depth, and the modulus of section; that is to say, maximum efficiency will be attained when all the resistant factors are a maximum for any given sectional area, after due allowance has been made for limits of production.

If reference be made to a complete list of rolled steel joist sections it will be seen that amongst the large sections the 20in. × 6¼in. joist (rolled by Dorman, Long & Co.) is considerably more efficient than the British standard joists of similar dimensions and area, for the simple reason that its proportions, as measured by the basis hitherto referred to, are more perfect. Taking this joist as representing the practical limit of efficiency and X as the coefficient of efficiency, where

W = weight per foot,

D = depth in inches,

Z = modulus of section,

then with these factors as a basis

$$X = \frac{W \times D}{Z} = \frac{65 \times 20}{117.8} = 11.036.$$

Compare the 18in. × 7in. section. Here

$$X = \frac{W \times D}{Z} = \frac{75 \times 18}{127.6} = 10.6.$$

Compare the 4in. × $1\frac{3}{4}$in. × 5lbs. section. Here

$$X = \frac{W \times D}{Z} = \frac{5 \times 4}{1.834} = 10.9$$

Now if X can have a value of about 11 for a 4in. and a 20in. joist, then there can be no reason why any intermediate section should not have a similar value, and a chart is given (Chart No. 1) on which has been drawn an efficiency curve with the basis $X = 11$ for variable weight-moduli. At suitable intervals along the curve suggested joist sections are indicated which if adopted by the British Standards Committee would give us a complete range of sections having the maximum theoretical efficiency obtainable from the present limits of production.

It will be noted that if a common factor of 11 exists for all sections this factor may be used to simplify calculations.

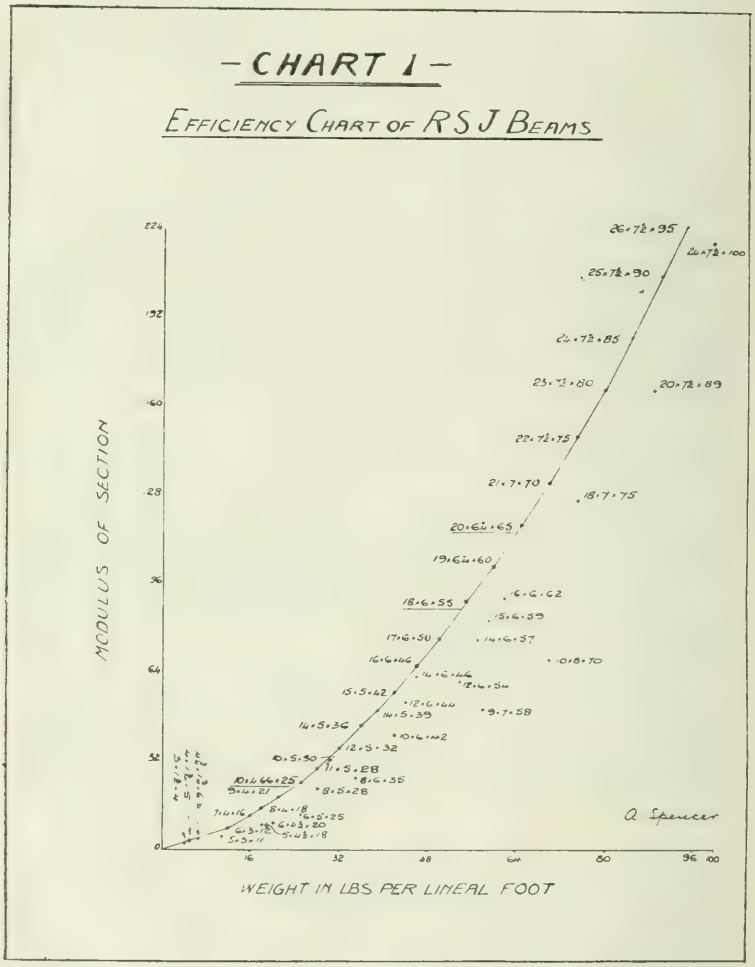
It should be particularly noted that some of our present sections lie on the efficiency line and that others do not, the maximum of inefficiency for joists used as beams being reached the farther away the particular joist is from the line. The 10in. × 8in. and 9in. × 7in. sections are particularly inefficient, as is well known.

A similar criticism may be applied to the inefficiency of our joist sections when used as struts. This has been recognised, probably, by the originator of the broad-flange beam, yet although the latter type of beam has been in existence for many years, its use has not been encouraged in this country.

It is very desirable that a more efficient range of joist sections should be obtainable, as under the present circumstances we are making a costly misuse of material and seriously jeopardising our position in competing for international trade in structural work.

Another instance of the lack of appreciation or of the disregard of the principle referred to is our rule-of-thumb method of arriving at the resistant lever arm for such triangulated framework as lattice girders, cantilevers, in-

clined braced struts, and so on Chart No. 2 has been compiled to show efficiency curves for four different types of triangulated framework. There are, of course, both



theoretical and practical curves, the latter being a modification of the former after taking into account auxiliary parts such as connection plates. The curves shown are approxi-

mate practical curves after taking into account such modifications. In compiling these curves a system of measurement was adopted which took into account the stress and volume of the members; that is to say, the effect of the load was arrived at, for purposes of comparison, as follows :—

(1) Stress calculated for each member.

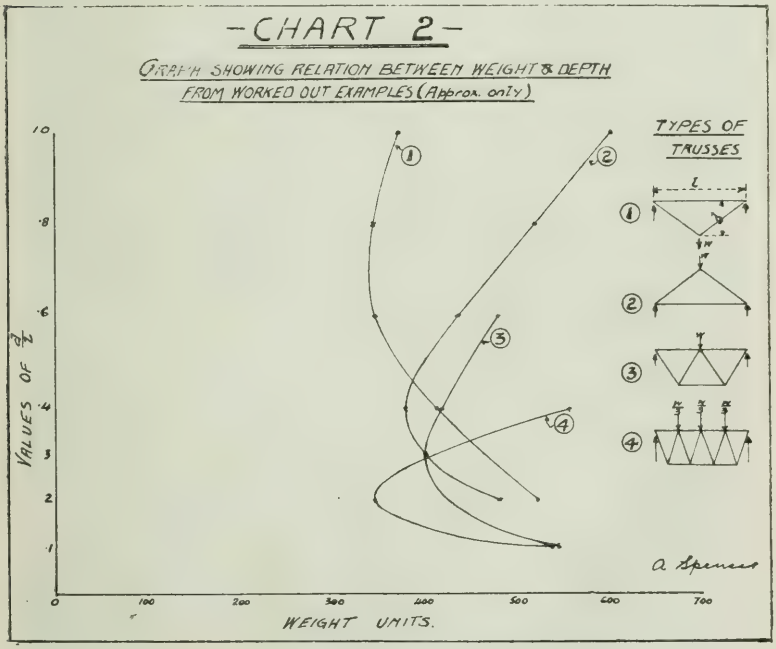
(2) Stress in each member was multiplied by its length.

(3) Compressive stress was multiplied by 2 to give the approximate equivalent to tensile stress.

(4) All principal stresses were reduced to equivalent tensile stress, and by process 2 the stress-volume of each member was obtained.

(5) The stress-volume of the members was added together to give the total value for the complete part.

The point to be emphasised here is that these curves shew that our present ideas of relative depth to span are



inefficient and need to be modified. Whether this contention is accepted or not, it must be admitted that we have no scientific simplified data available as to the most efficient ratio of depth to span for various types of triangulated or plated framework, and it appears to be advisable that some scientific body should look into this question.

Unit Stress.—The proper use of materials so as to take advantage of the variable utility of constructive materials is generally understood. By way of illustrating this point reference may be made to reinforced concrete construction, in which a compound material composed of concrete and steel is used in such a way as to enable the concrete (which is strong in compression and weak in tension) to resist the compressive bending stress, whilst the tensile bending stress is resisted by the steel reinforcement. Another application is the placing of the diagonal web members of a timber truss in such a direction as will subject the member to a compressive stress in preference to a tensile stress, timber being stronger in compression than in tension.

Selection of Sections.—The total number of sections in any given structure, particularly if speed of manufacture is essential, should be kept to a minimum, and theoretical considerations should be subordinated to practical necessity. This procedure enables the manufacturers of structural steelwork to keep a good stock of those materials most commonly used; and where it is necessary to order materials specially from the rolling mills, since certain sections are only rolled at certain periods, it follows that the fewer the sections the greater the tonnage of any particular section; and consequently the delivery of the whole will be accelerated, particularly as the rolling mills regulate the rollings in accordance with the demand.

Price lists should be referred to for the purpose of determining the most economical sections to use. For instance, until recently 3in. × 3in. angles, although heavier and considerably stronger than 2½in. × 2½in. angles, were cheaper per lineal foot than the latter section. Many a designer has secured an order for his firm by taking full advantage of such matters.

Coincident Forces.—In locating the various members of a structure, or part of a structure, their position should be such that the centre of resistant action should coincide for economic reasons with the centre of action of the applied

force. This principle is often violated for practical purposes —for instance, to simplify the connection in fixing the position of the members of a roof truss. This departure is permissible, but where the effect is considerable, as a force-moment of serious magnitude may be created, due allowance should be made for its resistance. The principle is often violated also in the design of connections by locating the rivets or bolts in such a way that the resultant resistance force does not coincide with the applied force, with a similar result to that hitherto referred to.

Practical Application of the Theory of Structures.

Of the two principal aspects of structural design—theoretical and practical—the latter has not been so well treated as the former, probably owing to the reason that literary ability is rarely attained by the practical designer until late on in life, by which time he is generally absorbed in the commercial side of the business and has no inclination to tackle the laborious task of placing his experience at the disposal of the younger generation. To anyone conversant with present drawing-office practice it is apparent that there is a wide gap in our system of technical education, since the majority of our young engineers obtain only a superficial knowledge of the vital principles of the theory and of its practical application. The primary reason is probably due to over-elaboration in mathematical reasoning. Mathematical reasoning is an abstract method, and the young engineer is too early presented with the problem of assimilating concurrently two lines of thought; and his struggles in the intricacies of mathematics obscure the important mechanical principles, a knowledge of which is really the end desired. The whole of the theory necessary to determine the stresses in structures which are statically determinate can be taught very simply, certainly much more simply than at present, and by this process the young engineer would be able to concentrate on the end desired, and his vision would not be so much concentrated on the means to the end. He would get such a grounding in first principles that he would never forget them.

As an illustration of over-elaboration in mathematical expression an example may be quoted of a formula in a certain book dealing with the theory of reinforced concrete. This particular formula is given as a means to obtain the proportions of a double-reinforced concrete beam subject to bending stresses, and it extends the whole width of the page. Now I am not suggesting that the width of the page

influenced the author in limiting the extent of the formula, but, joking aside, the formula is unwieldy in its practical application owing to the compiler having thought it necessary to take into account the small portion of concrete displaced by the steel reinforcement. The author might have given a simplified formula by omitting this mathematical nicety, protecting himself from criticism by stating that the omission represented a 1 per cent. error or thereabouts, a liberty which anyone acquainted with reinforced concrete construction would freely permit. A considerable proportion of the designing of structures is, rightly or wrongly, undertaken by engineers who have neither the capacity nor the time to utilise such indirect methods, and it may be safely stated that many young engineers are discouraged, or alternatively, they are limited in knowledge, through lack of scientific data presented in such a way as to be easy of assimilation. I am referring, of course, to such data as can be presented in such form. The student would have a better grounding in the theory of design if the principles were taught as far as possible without reference to mathematical expression. The teaching of mathematics may be left to precede the advanced Theory, for the understanding and application of which it becomes a necessity.

Another reason is that of using indirect methods to ascertain the magnitude of certain stresses instead of explaining how these stresses are set up.

There is a widespread misunderstanding, for instance, of the cause of horizontal shear in structural units subject to flexural stresses, and also of the mechanical law that stress is proportional to strain within the elastic limit. Many designers are unable to define correctly the logical sequence of the effects of a load applied to a beam. A surprisingly large number of structural designers are unable to determine rationally the number of rivets required to connect a gusset plate to the boom of a girder or principal rafter, even when the stress in the rafter at each side of the gusset is given, which goes to prove that they do not understand horizontal shear force. A thorough knowledge of internal stresses in solid rectangular beams is a necessity for the efficient design of reinforced concrete beams, yet many designers are deficient in this respect, due principally to mathematical application as hitherto referred to.

Principles of Statics.—A full consideration of the fundamental principles of Statics is beyond the possibilities of

this paper, but attention may be directed to those which are most often misapplied. These may be enumerated as follows :—

(1) Stress is proportional to strain within the elastic limit.

(2) The modulus of elasticity is that force which would strain or deform a bar to a length equal to twice its original length, assuming stress proportional to strain without limit.

(3) The distribution of bending stress is variable throughout the depth, and is a maximum at the extreme fibres.

(4) The neutral axis is the plane of zero bending stress.

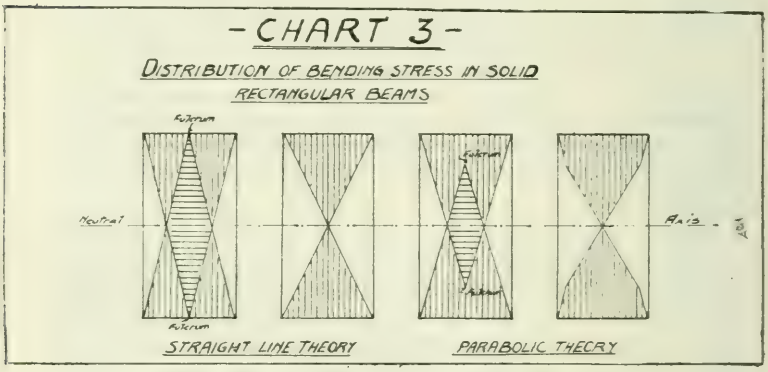
(5) Horizontal shear force is the result of the increment of bending moment.

Points 1 to 4 have a vital influence on the determination of the moment of resistance of a beam, and a description of the method of finding the elements which go to make up the moment of resistance of a reinforced concrete beam will be interesting.

The extreme fibre stress—that is, the economic value—is used as a basis for the determination of the neutral axis as follows :—Taking the compressive value of the concrete at, say, 600lbs. per sq. in. and the tensile value of the steel at 16,000lbs. per sq. in., then as the modulus of elasticity of steel is 15 times greater than that of the concrete (this varies according to the proportions of the concrete), it follows that the concrete in the plane of the steel will only be stressed to one-fifteenth that of the steel, otherwise the deformation of the two materials would be unequal; there would be no contact between the two materials, and therefore no homogeneity, which is an essential condition to ensure resistant lever action. From these relative stresses the neutral axis is located as follows :—As the stress in the concrete in the plane of the steel reinforcement is stressed to 16,000lbs. ÷ 15, namely, 1,066lbs., and the stress on the compressed outer fibres is only 600lbs., as strain is proportional to stress, the deformation at these planes is unequal since the stresses are unequal, and therefore the position of the neutral axis will be nearer to the compressed edge and its position relative to either plane will be proportional to the stresses. Taking the stresses referred to, the distance

of the neutral axis from the compressed edge will be represented by 600, and from the steel plane the distance will be 1,066. These two values may be simplified in terms of the depth of the beam, the value 600 as .36d and the value 1,066 as .64d.

With regard to the variable distribution of stress, there are two theories regarding the exact nature of the variation, the straight-line theory and the parabolic theory, the former being preferred owing to its simplicity, although the latter is probably more correct. The basis of the straight-line theory is that the cross-section of the beam simultaneously acts round two fulcra, one of which is in the plane of the



outer compressed fibres and the other in the plane of the steel. The basis of the parabolic theory is that the fulcrum in the compressed half is situated at the centre of action of the area of concrete subject to compression, and not at the upper edge. Chart 3 shows the construction of the resistance figure for each theory, and illustrates the variation in the distribution of stress in the two methods.

The resistant lever arm is greater for any given section by the parabolic theory than by the straight-line theory, and as the area of the parabola is greater than the area of a triangle with similar base and height, the total resistance of the compressive area is also greater. It will be noted that the error in the straight-line theory is on the side of safety.

With regard to horizontal shear force the misunderstanding of this force is due to lack of knowledge of its cause. Many designers, knowing that unit horizontal shear stress is everywhere equal to unit vertical shear stress, do not trouble about its cause, and are thereby led astray as to its effect.

Horizontal shear force is the effect of the increment of bending stress. The logical sequence of cause and effect applied to a beam under load is as follows :—

The first effect of load applied to a rigid beam is to apply pressure to the supports; this pressure may be, in effect, considered as a negative force or reaction and the load a positive force. These two forces are opposite in action, and consequently where they vary in amount a shearing force exists which is termed a vertical shearing force.

As the negative and positive forces have a moment, a force-moment is created which is termed a bending moment, which represents the difference between the positive and negative moments. This bending moment must, to preserve equilibrium, be resisted by a resistance moment of equal amount, which resistance moment is supplied by the beam itself, by virtue of material suitably distributed above and below the neutral axis, so as to create a resistance force couple, or, in other words, a resistance force-moment. Where there is an increment of bending moment there is in consequence an increment of bending stress, and it is due to this increment that horizontal shear force is created. Taking the case of a beam with imaginary vertical layers, the bending stress on one vertical plane of such a layer is greater than the bending stress on the other vertical plane; consequently as these two stresses are opposite and unequal there is a tendency for this vertical layer to be sheared horizontally in a direction coincident with the action of the greater stress.

The misunderstanding of horizontal force leads to serious mistakes on the part of designers, such as the one previously pointed out, where designers habitually blunder in determining the number of rivets to connect a gusset plate to the boom girder or principal rafter. Many designers have put forward arch theory and suspension theory as being preferable to beam theory for the design of reinforced concrete beams. Viewed in a proper perspective, there is

no substantial difference between these theories. The difference between the arch and the suspension cable on the one hand and the beam on the other hand may be confined to the nature of the reactions. In the arch and cable the reaction will be inclined, whereas in the beam the reaction will be vertical; I am referring, of course, to an instance where the loads are vertical. If the arch or the cable is supplied with a horizontal member, this eliminates the horizontal component of the reaction, and it is then questionable whether the structure be referred to as an arch or cable on the one hand or a beam on the other hand. Where the centre of resistance of the arch and cable does not conform to the centre of action of the force, or, in other words, the equilibrium line, then flexural stresses exist and the structure has to resist direct stress in addition to flexural stress, and it is now a question as to whether the structure should not be termed a beam. Whatever description is agreed upon it should be noted that flexural stress exists, and if such stress is variable then this increment of bending stress creates a horizontal shear stress.

There are many designers who contend that a reinforced concrete beam is really an arch, and consequently there is no increment of bending stress and therefore no horizontal shear. On this assumption they contend that shear members are not necessary, and therefore that the adhesion between concrete and the tensile reinforcement is not important, and in fact can be ignored, providing the ends of the reinforcement are hooked over, so that the tensile force in the reinforcement is resisted at the ends. Where there is an increment of bending stress (which exists in the majority of beams) then this opinion is fallacious, since the existence of horizontal shear force is obvious.

The reason for superseding beam action by arch action does not therefore appear sound, and certainly there does not seem to be any economy in the one as compared with the other.

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The Geology of Sands and Aggregates for Concrete Making.

With Especial Reference to Texture.

By P. G. H. BOSWELL, D.Sc.

The essential constituents of concrete are the aggregate, or lumps of broken materials, and the matrix, or binding substance, which is usually cement or lime. Frequently sand is also added to the mixture, or a fine-grained concrete may be made from sand and cement alone. The American connotation of the term "aggregate" includes sand.

In the specifications of the British Fire Prevention Committee the aggregates listed have been divided into two classes, natural and artificial. All the natural aggregates are necessarily rock substances, the description and occurrence of which come within the purview of geological science. The artificial aggregates result either directly, or as by-products, from the applications of industrial processes to geological materials. The natural aggregates include gravel (ballast), igneous (or fire-formed) rocks such as granite, basalto and other lavas, pumice, etc., and sedi-

mentary rocks like sandstones, quartzites, limestones, etc., which were originally deposited under water or by wind, but which may have been subsequently altered by earth stresses or heat. The artificial aggregates include coke breeze, clinker, blast furnace slag, brick and terra cotta, and burnt clay. Materials analogous to all these artificial aggregates occur among the rocks of the earth's crust and have been produced in each case by the action of heat upon pre-existing rocks.

It is, however, with the geology of natural aggregates (which are used, except perhaps for the crushing, screening and washing, in the state in which they are wrought) that the following notes are concerned.

The Geology of Aggregates.

The rocks, which form the earth's crust, are classified into three groups according to their mode of origin. Those which have resulted from the cooling of molten magmas are known as *igneous* rocks, and their texture may vary from coarsely crystalline to glassy, according as they have cooled slowly or rapidly. Where steam and other contained gases have blown the rock into a froth, the material known as pumice is produced.

The decomposition of igneous (and other) rocks under the influence of such geological agencies as frost, rain water and heat, aided by running water and wind, results eventually in the accumulation of the débris at the bottom of the seas, lakes and rivers, or even scattered over the land. On account of the way in which they have arisen, such detrital rocks are known as *clastic* or *sedimentary*, the former term serving to remind us that they are composed of broken fragments of minerals or other rocks. Included in the "clastic" group are also rocks composed of the fragments and dust blown from volcanos during their eruption.

Both igneous and clastic rocks may be subsequently altered as a result of the action of either heat alone (by contact with injections of molten magma) or of intense earth pressure, when the energy is frequently dissipated in the form of heat. In this way rocks belonging to the third group may be produced; they are said to be *metamorphic* because of the changes in mineral constitution and texture which have been produced in them.

In all the important industrial applications of rocks attention has to be paid either to the mineral composition or the texture—or frequently to both. The making of concrete proves no exception to the rule, but the present state of knowledge as to the effect of mineral constitution or even the ultimate chemical composition upon the setting of the concrete is not so complete as might be desired. Much more information regarding the effect of the size and shape (that is, the texture) of the aggregate upon the strength and durability of concrete is available.

When the number and variety of rocks used as aggregates are considered, it becomes evident that in a paper of ordinary dimensions no attempt can be made to describe all in detail.

The Classification of Aggregates.

In the specifications of the British Fire Prevention Committee* a not entirely inappropriate grouping (so far as use is concerned) of natural aggregates is made. Broken stone is classified thus :—

Ballast (gravel).
Volcanic rocks—(*a*) Basalts and dense rocks.
(*b*) Lavas.
(*c*) Pumice.
Granite.
Sandstones, limestones, quartzites, etc.

The geological purist would prefer to see the group of sandstones and quartzites more closely associated with ballast (gravel), to which these stones are genetically connected, and from which they differ only in grade. Limestones, both on account of their very different chemical composition, texture and fracture, as well as their different behaviour (at times) in the setting of concrete, might with advantage be placed in a class by themselves. Quartzites, sandstones, sand, gravel and limestones, would then form a sedimentary division, leaving "granite" and "volcanic rocks" to be placed in another division—the igneous rocks. The term "granite" in industry is reminiscent of the charity which covers a multitude of sins. Apparently, any rock which is reasonably hard, and which can be used for road material or paving setts, is termed granite. Not only are basalto and

* The writer understands that these specifications at present undergoing entire revision. The results, however, are not yet published.

similar lavas included in the term, but even the quarzites of the Midlands, purely sedimentary rocks, have also been similarly classed. It is a pity to spoil a good term in this way, even although it may not always be desirable or necessary to introduce too much rigidity of scientific nomenclature into industrial practice. In the strict geological sense, a granite is a crystalline rock, which is the result of the slow cooling and crystallisation of a molten magma rich in silica. The cooling has usually taken place at considerable depth and under great pressure, and as a result the constituent minerals are equi-dimensional and well developed, and the rock therefore coarse-grained in texture. Granites consist of 70 per cent. or more of silica, which is partly present as quartz and partly in the form of silicates, such as felspars, micas, and other minerals like the amphiboles and pyroxenes. Coarse-textured rocks, like granite, which have originated in depth, are said to be " plutonic," and under this heading are included other rocks known as syenites, diorites, gabbros, etc., which have cooled from magmas of different chemical composition (for example, of decreasing silica content). The transition from granites to syenites and diorites is gradual, and it is not always easy in hand specimens to classify exactly any particular rock. No great harm would result commercially in many directions from calling all these plutonic rocks " granite " on account of the similar mode of origin (although the writer, as a geologist, would not be permitted to recommend such a plan). Before doing so in concrete specifications, however, it might be well to determine experimentally the effect in the aggregate of decreasing silica and increasing lime and magnesia (in the form of silicates) upon the setting qualities of concrete.

Under the heading of " volcanic rocks " in the specification are included separately " basalts " and " lavas." But basalts *are* lavas. Lava consists of rock, either fluid or congealed, which has been extruded at the surface of the earth and so has cooled under air or water. The association of the expression " dense rocks " with " basalts " in the grouping rather suggests that by basalt was meant a compact rock free from vesicles produced during solidification by escaping steam and gases, and by " lava " a vesicular or amygdaloidal rock. But many basalts are amygdaloidal (for example, the well-known Giant's Causeway rock), and some lavas are very compact.

Undoubtedly under the heading of basalt is included the group of rocks known to geologists as " hypabyssal,"

that is those cooled relatively near the earth's surface, intrusive into other rocks, but not extrusive into the atmosphere or sea. In this case the cooling is more rapid than that of plutonic rocks (the pressure probably being considerably lower) but slower than that of most lavas or volcanic rocks. Amongst the hypabyssal rocks are the "whin-stones" (dolerites) worked so extensively in many parts of the British Isles for road metal, paving setts, etc. They occur as dykes and sills intruded into sedimentary rocks. "Porphyries" are the hypabyssal equivalents of the granites and syenites, and dolerites are the rocks corresponding to the diorites and gabbros.

A more natural grouping of the specified rocks would therefore be:—

A. Sedimentary rocks.

(1) Sandstones and quartzites.
(2) Sand.
(3) Ballast (gravel).
(4) Limestones.
(5) Granite and other plutonic rocks.
(6) Hypabyssal rocks, such as trap, whin-stone (dolerite), etc.
(7) Compact volcanic rocks such as basalt.
(8) Vesicular lavas, pumice, etc.

Texture of the Aggregate.

For concrete making it is of importance as well as interest to know how coarse in texture the rock fragments may be and the character of their fractured surfaces. The latter depends upon their mineral constitution, which may also affect the setting of the cement. To quote a somewhat analogous instance from road materials, some of the best "metals" in use are the rocks included in the dolerite-diorite group. The physical properties (hardness, coefficient of expansion, etc.) of the various constituent minerals, such as plagioclase felspar, pyroxene, hornblende and olivine, are in many respects somewhat similar. The rock therefore fractures evenly into roughly cuboidal or tetrahedral forms and the minerals tend to wear away at about the same rate, which would not be the case if a harder and more chemically stable mineral, such as quartz, were present. Other questions, which are concerned, for example, with binding qualities, dust-production, etc., have also to be considered.

We may now examine briefly the textural qualities displayed by the various rock types used as aggregate.

A. Sedimentary Rocks.

Sandstones and Quartzites.—Sandstones and quartzites are the indurated rocks corresponding to sands. The cementing material may be—

(1) Silica itself, as in siliceous sandstones and quartzites.

(2) Clayey matter as in argillaceous sandstones (which upon metamorphosis yield micaceous quartzites or quartz-schists).

(3) Oxide of iron, either as hematite ($Fe_2 O_3$), which is red; or limonite, which is hydrated and is yellow or brown ($2 Fe_2 O_3, 3 H_2 O$).

(4) Calcium carbonate, as in calcareous sandstones, or dolomite ($[Ca, Mg] CO_3$) as in the well-known Mansfield building stone.

(5) Other less important minerals such as phosphates, fluor-spar ($Ca F_2$), barytes ($Ba SO_4$), etc., which do not concern the concrete maker intimately.

Of the above cements the siliceous is undoubtedly the best for the purpose now being considered. It is generally accepted that soft sandstones are to be avoided for concrete; practically speaking, the bond is rarely siliceous in soft sandstones. The matrix of silica leads to great strength and clean sharp fracture of the rock, firstly on account of its hardness, and secondly because the silica frequently grows crystallographically on and in optical continuity with the surface of the quartz grains (being of the same chemical composition). The individual grains thus grow until they meet one another and interlock firmly. The structure can best be seen in polarised light under crossed nicols.* Rocks of this character break across the sand grains and matrix equally and yield smooth plane surfaces and sharp edges. Soft sandstones may also be converted into quartzites of this type by re-crystallising effects of heat, or of earth stresses during mountain-building movements. Such quartzites would belong to the metamorphic class of rocks.

Cementing by argillaceous matter does not yield the best type of sandstones for aggregate, nor do the results of metamorphism upon such rocks yield a satisfactory product

* The structures mentioned are all illustrated by lantern slides.

(see below). The latter is often a mica-schist or similar foliated rock.

Certain workers at the subject have stated that, far from being inimical, iron oxide in rocks may be useful on account of the chemical reactions into which it enters with the cement. Unfortunately most sandstones cemented with this substance do not show a desirable degree of compactness; a few, however, such as the Carstone of the Lower Greensand, particularly from Norfolk to Oxfordshire, are fairly hard.

Calcareous cements may be chalky and amorphous in character (when the resulting rock is soft) or composed of crystalline calcite (when a hard compact stone may be yielded). In the latter case, as in quartzites, the fracture of the stone breaks across the sand grains and not round them—a very desirable property in concrete making. Occasionally " in the field " we meet with natural concrete—known as " calcrete "—formed by the cementation of sands and pebble beds by lime originally in the form of carbonate. The matrix frequently now shews no effervescence at the present time with acid, tricalcic silicate having probably been formed, as in the setting of cement. Calcite can be scratched with a knife; quartz cannot. Aggregate of calcareous sandstone therefore shews heterogeneity in hardness as well as composition.

Portland cement containing more than 8 per cent of magnesia is objected to on the grounds that expansion and loss of strength are likely to occur in the course of time. It would therefore appear that sandstones cemented with dolomite should, if possible, be avoided.

Other cementing media are of local occurrence only and are mainly of geological interest.

Sand.—The texture of sand, which is frequently used in addition to other aggregate, is considered separately in a later section of the paper.

Ballast (Gravel) is usually incoherent, as in the case of " Thames ballast." The question of cementing material therefore does not arise. Many of the pebble beds used for concrete-making are of comparatively recent geological age. As examples may be quoted the Eocene pebble-beds of the London Basin, or the Glacial gravels, which are more widely distributed. Most of the Eocene gravels consist of well-rounded black flint-pebbles, an occasional quartz or quartzite

pebble being found. To destroy the uniformity of size and roundness, they should be broken before use in concrete work. The glacial and river gravels are less uniform in rock character, size and shape, and their composition varies according to the geology of the gathering ground. These gravels are also improved by being broken up. Washing, especially of glacial and recent gravels, is desirable to clean them from adherent clayey and calcareous material.

Extensive pebble-beds, composed of rounded quartzite pebbles, occur in the Bunter beds throughout England and also in the glacial and river deposits formed from them (*e.g.*, near Doncaster, etc.). The pebbles are mainly about the size of the fist, and after crushing yield an admirable concrete-making quartzite material which has not been used as widely as it might. Very little washing of the crushed product would be necessitated. Resources are available in Devonshire, Dorset, the Midlands (near Birmingham), Derbyshire, Nottinghamshire, Yorkshire, etc.

Limestones.—Limestones may be produced by organic action or by chemical precipitation from the waters of lakes and seas. The former group includes rocks made up of the calcareous skeletons, shells, etc., of lowly plants and animals, usually bound together with amorphous calcareous and clayey, or even sandy, material. On the other hand, the latter group consists of rocks which are crystalline and homogeneous in character. Similar limestones, composed entirely of interlocking grains of the mineral calcite, may be produced as a result of recrystallisation of limestones of organic origin under great heat or pressure. Such crystalline limestones (marble, etc.) are therefore metamorphic in origin. Oolitic limestones are those composed of small roe-like grains cemented together by calcareous material. The grains have been formed by segregation of the same material round some nucleus, during which time the grains were kept rolling along the shore.

Soft limestones are not suitable for concrete making, nor, on the whole, are those of organic or oolitic origin. They tend to break and flake irregularly, and an oolite rarely breaks across the grains. Crystalline limestones have a sharp clean fracture and are homogeneous, but glide-planes are very easily set up in calcite crystals by pressure. Calcite has also an excellent cleavage; deformation and fracture are thus liable to take place. Limestone is neither as hard, nor structurally as strong, as quartzite.

B. Igneous Rocks.

Granite and other Plutonic Rocks.—Whereas most sedimentary rocks consist of grains cemented together by chemically similar or dissimilar material, igneous rocks, from their very mode of origin, are made up of grains of minerals crystallised together. Various types of structure are produced, but the essential feature is the close contact and interlocking of the grains.

The plutonic rocks, having cooled slowly and often under great pressure, are coarse-grained and the individual minerals are on the whole equi-dimensional. This texture has been termed *granitic* from its being exhibited so frequently by granites. Where the individual minerals tend to take a somewhat rounded shape and uniform size, the texture has been called *granular*. In the diorites the grain is as a rule smaller than in granites. The constituent minerals of a typical granite are quartz, felspar and mica; hornblende and pyroxene may also be present. Quartz is much harder, and less prone to chemical decomposition, than the other minerals mentioned. Although these differential qualities might affect the value of crushed granite as a concrete-making material, most writers on the subject see little difference in the results yielded by granite and diorite, which is largely composed of felspar and hornblende or pyroxene, minerals more similar in hardness and in proneness to decay.

Hypabyssal Rocks.—Many of the "traps" and "whin-stones" are finely granular in texture, the individual crystals being too small to be seen by the naked eye. Occasionally there are larger crystals, known as *phenocrysts*, set in a fine ground-mass of small crystals. The structure is then known as *porphyritic*. The phenocrysts are large enough to be detected in hand specimens of the rock. Another structure frequently shown by members of this group of rocks is that known as "*ophitic*" from its snake-like appearance. During cooling, one of the minerals has crystallised out in aggregates of somewhat lath-like form, which interlock with and wrap round other constituents of the rock. Frequently each of the aggregates behaves under polarised light as an optically continuous crystal. The minerals, felspar and augite (pyroxene), which are commonly the constituents of dolerites, exhibit this feature well. Undoubtedly ophitic structure leads to density, sharpness and cleanness of frac-

ture, and strength in concrete-making aggregate. Dolerites, traps, and whin-stones are therefore popular materials. Microgranites are the hypabyssal equivalents of the granites and show a fine-grained granitic structure.

Compact Volcanic Rocks.—The important members in this group, arranged in order of decreasing silica-content (and therefore of increasing specific gravity), are Rhyolites, Obsidian, Pitchstones, Trachytes, Andesites and Basalts. Rhyolites and Trachytes are frequently not as compact as the others; moreover, although they have been employed, they are of too limited distribution in the British Isles to be used extensively for aggregate. The rock "felsite," which is worked in North Wales, Cornwall and other districts for road material, is sometimes of hypabyssal origin (corresponding to the plutonic rocks, granite and syenite), and at others has resulted from the chemical alteration of rhyolites and trachytes. It is usually very fine grained and compact, and sometimes shows phenocrysts of quartz, felspar, etc. As a concrete aggregate it would doubtless prove satisfactory.

Andesites and basalts are micro-crystalline to glassy in texture and are frequently porphyritic. Some of the coarser basalts exhibit ophitic structure. The term "whin" often includes basaltic rocks.

Vesicular Lavas (Pumice, etc.).—The decrease in pressure which accompanies the extrusion of a lava at the surface of the earth results in the release of contained gases, steam, etc., which render the upper part of the flow frothy, and cause the bulk of the rock to be riddled with steam-holes, known as vesicles. Often these are drawn out into almond-shaped cavities by the sluggish flow of the congealing rock. The cavities may be filled in subsequently by minerals which have crystallised from solution (amygdales, *amygdaloidal* structure). The fracture of such rocks is irregular, and the voids are great.

Metamorphic Rocks.

It does not appear that apart from quartzite and crystalline limestones, rocks of metamorphic origin have ever been extensively used in concrete work. They are not specifically mentioned in British specifications; in the American connotation of the term "granite," however, both gneiss and mica-schist are included.

Gneisses and schists result from the metamorphism of both igneous and sedimentary rocks, and are characterised by complete recrystallisation of the contained minerals. This phenomenon has frequently taken place under pressure in such a way that the minerals have been orientated until they lie like leaves of a book, arranged perpendicularly to the pressure. The structure is then said to be *foliated*, and the rocks tend to split easily along the foliation planes. This tendency to splitting and spalling prevents their being dressed into equi-dimensional lumps and renders them of less value for concrete than many sedimentary and igneous rocks.

Even quartzites and limestones may not only be recrystallised but may have their grains drawn out into lenticles under pressure. Where the minerals have objected to this "rolling out" process, and break into rounded grains, the structures known as *granulitic* and *morter-structure* (mörtel-struktur) are produced.

SANDS FOR CONCRETE MAKING.

Sand, as previously noted, may be regarded as an aggregate itself or as a third constituent in concrete. It is used so extensively for mortars and concretes as to justify a separate treatment. Materials like sand, loam and clay are as much rocks to the geologist as granite and basalt.

Sand plays the rôle in concrete-making of a filling material intermediate in size between the aggregate and the cement. It therefore tends to assist the production of smooth surfaces. To obtain a minimum of voids and a maximum of strength the gradation of the sizes present in the aggregate should be as perfect as possible. Any attempt to carry this proportional spacing of weights of aggregate over grade-sizes down to sand would lead to the production during crushing of large quantities of dust and fine material (see Fig. 1). Much washing would therefore be necessitated. It is more advantageous to break and screen the aggregate down to the size of very coarse sand (say 20-mesh) and to fill in the smaller voids with coarse and medium sand (50, to 20 or 30 mesh). Fine sand has been found to weaken the strength of the concrete. On the same principle (of perfect spacing of grades) it is desirable that the sand used should not be "well graded," that is, have all its grains of the same diameter. Sand composed of mixed grades contains fewer voids and reduces the quantity of cement required.

Composition of Sands.

It may be well to consider briefly the special qualities required in sands used for concrete. Analyses of sands may be made from three different standpoints. They may be subjected to chemical analysis, and their composition expressed ultimately as a series of oxides. With few exceptions sands are found to consist of 80 to 99 per cent. of

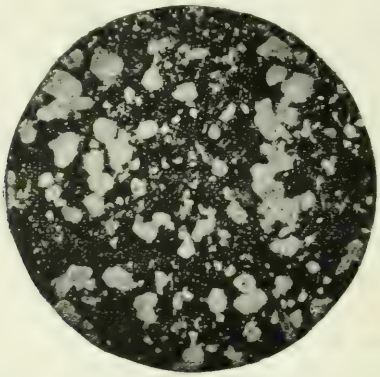

FIG. 1. × 20.

silica (SiO_2). Alumina (Al_2O_3), iron oxides (FeO and Fe_2O_3), lime (CaO), magnesia (MgO), and the alkalies—soda and potassia (K_2O and Na_2O) are the chief remaining constituents. As an example we may quote the analysis of a sand from Leighton Buzzard, Beds., well known to those interested in concrete:—

	Leighton Buzzard Sand (washed). Chemical Analysis.
SiO_2	99.05 per cent.
Al_2O_3	0.23 ,,
Fe_2O_3	0.14 ,,
MgO	0.08 ,,
CaO	0.31 ,,
Na_2O	None.
K_2O	None.
Loss on ignition ...	0.31 ,,
	100.12 per cent.

Such a sand is, of course, exceptionally pure.

Sands may also be analysed from a mineralogical point of view. The variety and proportions of their constituent minerals are determined by certain special methods, a description of which may be found in modern geological text-books. Most sands consist largely of grains of quartz (SiO_2), but the common rock-forming minerals, the felspars (polysilicates of aluminium, lime and the alkalies) usually occur also, and with quartz constitute over 99 per cent. of the sand. Quartz has a specific gravity of 2.65, and that of the felspars, according to their chemical composition, varies from 2.56 to 2.78. The remaining minerals of sands include iron-ores and many mineral species of interest mainly to geologists. On account of their high specific gravity, these minerals are known as the "heavy minerals."

Texture of Sands—Mechanical Analysis.

Neither the chemical nor the mineral constitution of sands concerns the concretor very closely, although he uses them on account of their quartz-content. It is only when they contain the clayey decomposition products of the felspars and certain of the heavy minerals that he raises objections. Neither chemical nor mineral analysis (for mineral analysis merely shews the manner of grouping of the chemical elements) is required to reveal this material if it is present in any quantity. The third type of analysis, namely, mechanical analysis, does so at once. By the mechanical analysis of a sand or aggregate we seek to determine the sizes of the constituent particles or lumps, and the percentage weight of each portion between certain agreed limits of size ("grades"). A definite nomenclature for the smaller grades is very desirable in practice, and the following scheme, based on the metric system, has been found of great service geologically:—

Approx. I.M.M. Mesh.						
	G	Greater than 2.0 mm. diam.			Gravel Grade [G]	
12 5	VCS	,, ,, 1.0 ,,	and less than 2.0 mm.		Very coarse sand	Sand grade [S]
20 12	CS	,, ,, 0.5 ,,	,, ,, 1.0 ,,		Coarse sand	
50 20	MS	,, ,, 0.25 ,,	,, ,, 0.5 ,,		Medium sand	
120 150	FS	,, ,, 0.1 ,,	,, ,, 0.25 ,,		Fine sand	
180 120	cs	,, ,, 0.05 ,,	,, ,, 0.1 ,,		Superfine sand or coarse silt	Silt grade [s]
——	fs	,, ,, 0.01 ,,	,, ,, 0.05 ,,		Silt	
——	c		less than 0.01 ,,		Clay or mud grade [c]	

Mechanical analyses of aggregates as well as coarse sands may be effected by screening.

Except for the I.M.M. screens (that is, those conforming to sizes laid down in specifications by the Institution of Mining and Metallurgy) where the diameter of the square aperture is equal to that of the wire, no uniformity or standardisation in sieves exists. Moreover, they are only moderately accurate even when round-holed and made from perforated copper or brass. In any case, sifting is no longer possible for accurate separation when the grades are less than half a millimetre in diameter. Material of this size or less is analysed by the process known as elutriation, which consists in separating the sediment into grades by means of suitably-controlled currents of air or liquid (usually water). Elutriation by means of wind-currents is utilised industrially in cement manufacture and in the preparation of silica flour, in both cases after the final grinding. For scientific work, air separation is found to be insufficiently accurate and sediments are therefore subjected to mechanical analysis by elutriation, with upward currents of water as the lifting agents.

In view of the fact that the maker of concrete requires coarse sands, free from finer grades, silts and clayey matter, it is unnecessary to deal with elutriation in detail. It is generally agreed that the sand used should not be smaller than 30-mesh, or at the extreme 50-mesh material. The latter size corresponds closely to 0.25 mm., which, in the writer's opinion, is about the lower limit of possible accurate screening. Even at this point, elutriation yields more accurate results, since the size is too small for the making of round-holed screens.

The grain size is undoubtedly the most important factor in concrete-making sands, and it is frequently specified that the sand shall not be less than 30-mesh. The so-called "Standard" sand for cement testing, road-metal abrasion, etc., is defined in Britain and the U.S.A. as a natural sand which passes a screen having 20 meshes to the linear inch (0.63 mm. diameter) and is retained on a screen having 30 meshes to the linear inch (0.42 mm. diameter). In the classification adopted above, it corresponds most closely to the coarser part of the medium sand grade. The U.S. standard sand is wrought at Ottawa, Ill., and is a highly

rounded sand, as shewn in Fig. 2.* The British standard sand is worked at Leighton Buzzard, and is composed of subangular grains (see Fig. 3, which however is not of "standard" size).

The French Standard Sand is said to come from Leucate, France, and is simple or compound. The simple standard sand must pass a screen having holes 1.5 mm. in diameter (0.06 inch) and be retained on one having holes 1 mm. in

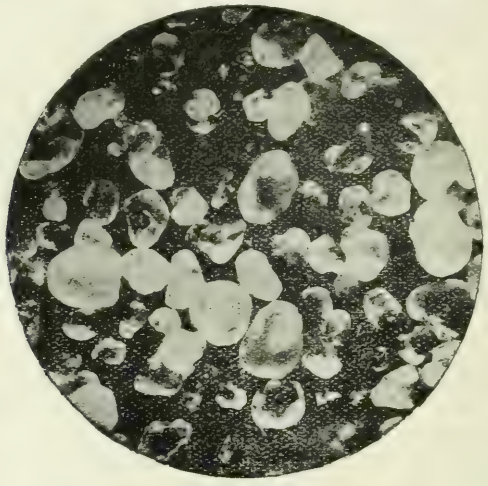

FIG. 2. × 16.

diameter (0.04 inch). The compound Standard Sand is made by preparing a mixture from equal weights of the following grades:—(*a*) 2 mm. to 1.5 mm., (*b*) 1.5 mm. to 1 mm., (*c*) 1 mm. to 0.5 mm.

The German Standard Sand corresponds to the British in size, but the major limit is slightly less (28-mesh). The Austrian Standard Sand is also of similar size.

It is noteworthy that most of the fairly pure British sands are of rather smaller grade than the Standard Sand. The sands from Spital, Huttons Ambo, South Cave, Fairlight (Hastings), Aylesbury, Aylesford, Godstone, Lynn and Reigate are examples in point. Although impure coarser sands are abundant in many geological formations and occur

* This example was not screened to 20-mesh.

plentifully as river and glacial sands, the Leighton Buzzard deposits remain practically the only pure coarse material.

The vast and unsightly tips of sand left as a result of the washing of decomposed granite in Devon and Cornwall

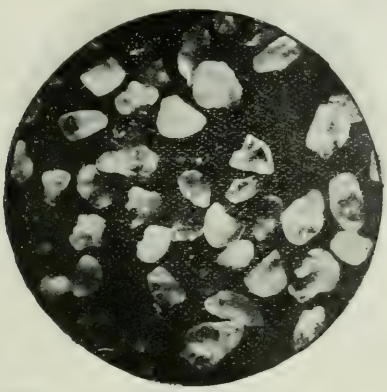

FIG. 3. × 20.

for the purpose of obtaining china clay are of the grade suitable for concrete. The material may be obtained cheaply and its utilisation would be a public service.

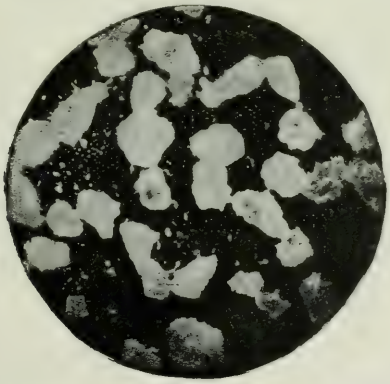

FIG. 4. × 21.

It would be desirable at some future time to place on record a full description of British resources of sands suitable for concrete-making. Similar accounts have been com-

piled, under war conditions, for the sands used in glass-manufacture and for refractory purposes. Sands of this character usually lie between 60-mesh and 30-mesh. The

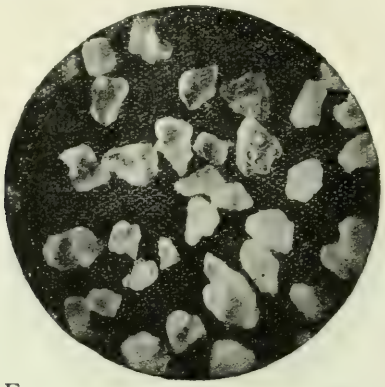

FIG. 5. × 21.

description of our home supplies of these materials is thus of limited value to the concrete maker.

Most British sands are subangular in grain, as shewn in Figs. 4 and 5. At a few geological horizons, notably

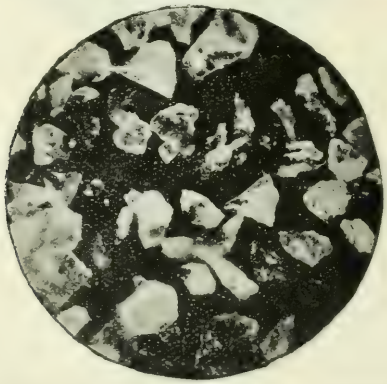

FIG. 6. × 21.

the Trias and Permian, rounded grains are abundant. The products obtained by crushing quartz are flaky and splintery, as shewn in Fig. 6, and are not suitable for concrete-

making on account of the excessive quantity of voids they yield. Flint is open to the same objection. The hardness of the mineral grains of a sand, and their freedom from cracks, etc., are matters of importance.

The opinion that there is little to choose in the use of sand between subangular or rounded grains is now gaining ground. As the rounded grains are usually not spherical, but ellipsoidal or egg-shaped, and the subangular grains are quite as nearly equi-dimensional, the voids yielded by one are hardly less than those of the other.

In a perfectly graded sand or aggregate composed of uniform spherical grains the percentage of voids varies according to the type of packing. Theoretically, the voids form 47.6 per cent. of the bulk when each sphere rests on one other; 39.5 per cent. when each sphere rests on two others; and 25.95 per cent. when each sphere rests on three others—obviously the method of closest packing. Other arrangements of the spheres also give the last result, which, as the late H. C. Sorby pointed out,* serves to indicate that even when occupying the least volume, the spheres could move about considerably without increasing the proportion of voids. Sands when deposited do not take up an arrangement leading to minimum voids. Shaking or compression, due respectively to earth movement or weighting by accumulated strata above, etc., may reduce their voids. In no case did Sorby succeed in reducing the voids even of fine sand below 34 per cent., the same sand unshaken having had about 47 per cent. voids. Sandstones, oolitic limestones and similar rocks may be regarded as natural concretes. It is therefore of interest to recall Sorby's work on the interspaces of such rocks. The cementation of the grains naturally reduces the quantity of voids, which often sink below 20 per cent. In certain cases the proportion falls to 6 per cent. and Sheffield Gannister, as a result of infilling by secondary quartz, contains less than 1 per cent. Little work has yet been done upon the grain size of sedimentary rocks which have been indurated and cemented.

Washing of Sands, etc.

The effective washing of sands and aggregate to be used for concrete-making is a matter of great importance. A

* See Quart. Journ. Geol. Soc., Vol. 64 (1908), p. 181. See also, U.S. Geol. Survey, Water Supply and Irrigation Papers, No. 67 (1902), and 19th Annual Report, Part V. (1899).

perfect solution of the problem cannot yet be said to have been evolved. Some method of "scrubbing" is the only way to clean ballast effectively from adherent clay and loam. On the other hand, the dust produced in the crushing of aggregate can easily be washed away. If the aggregate is required down to 50-mesh, an upward current of water at ordinary temperatures of about 5 feet per minute (or 1 inch per second) will remove all material smaller than this. If sand is to be added and the aggregate is in consequence required to be not smaller than 20-mesh, a velocity of about 15 feet per minute will remove the material not required. Many types of sand-washing machines are in operation throughout the country. They range from the crudest and most primitive forms to thoroughly up-to-date types. Fortunately the grade of sand required for concrete-making is a size which will wash without difficulty; considerable losses are experienced with fine-grained sands. The objection to most sand-washers in use is that the water first washes the dirty sand, and then, before it leaves the apparatus, is filtered again by the clean sand; much of the clayey and vegetable matter thus remains in the sand. In the writer's experience, the most effective sand-washing plants at present in operation are Rikof's apparatus* and the Dorr classifier. The results of effective washing of a sand are shewn in Figs. 4 and 5.

Graphical Representation of Grades.

A considerable amount of work has been done in the graphical expression of the grading of aggregate for concreting—more perhaps than in any other industry.† In many cases the object has been the synthetic preparation of mixtures. The principle adopted by the writer in expressing graphically the mechanical analyses of sands is similar to that in use for concrete materials, but there are slight differences in detail which may make it of interest to record the method. The expression of mechanical analyses in the form of curves brings out contrasts and similarities in sands and aggregates more graphically than does any other method. The curves are of course only approximations at the best. Cumulative percentages by weight of material

* For details see "A Memoir on Refractory Sands for Furnace and Foundry Purposes," p. 177. London, 1918: Taylor and Francis.

† See for example, Taylor and Thompson, "A Treatise on Concrete." 3rd Edn., 1916. New York

above the grade-size (marked horizontally) are set off vertically as ordinates. The horizontal scale adopted is proportional to the logarithms of the diameters marked, in order to keep the scale representing the various grades within the compass of the page.

Horizontality in any part of the curve means the absence of the material of the grade-size corresponding to the distance over which such horizontality extends. Verticality in the graph means a considerable percentage in the grade size corresponding to the position of the vertical portion. Some typical British sands expressed by this graphical method are represented in Fig. 7. It will be observed that only the

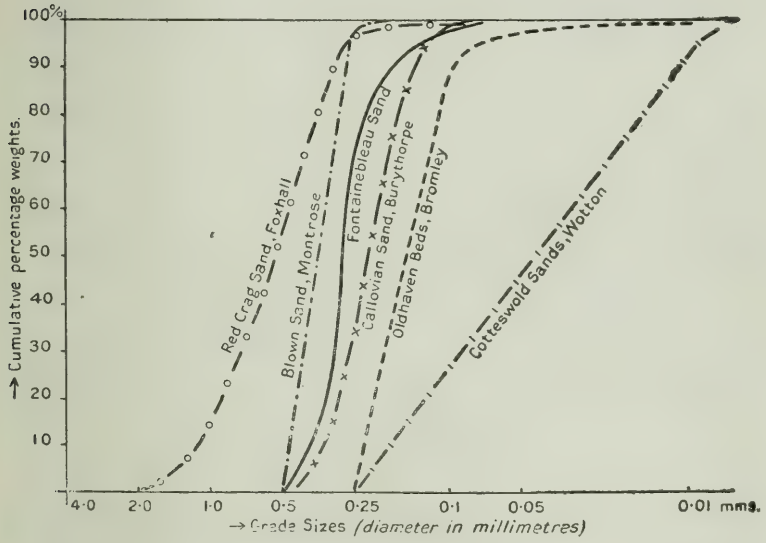

FIG. 7.—*Graphical Expression of Mechanical Analyses: possible variation in true sands.*

coarsest is suitable for concrete-making. The method of graphical expression here indicated is doubtless better suited for the expression of analyses of sediments bearing fine material than for coarse aggregates. In the former the larger limit of size of grains can be accurately determined, but the smaller limit is not known and its graphical expression would lie somewhere in the extension of the diagram towards the right.

In the above brief consideration of certain geological aspects of aggregates and sands for concrete-making, the field has been so large and time and space so small, that the account has necessarily rather taken the form of notes not always too well linked. It would have been desirable to have given a brief account of British resources of all the rocks mentioned—particularly of quarries, etc., where spalls left in the dressing of building-stones and setts are available. The fact that such information is not at present available serves to indicate the tendency, which has been universally shewn in the past, to record national resources of what might be called "precious" commodities like coal and metallic ores, but to ignore the "every day" materials like limestone, sandstone, gravel and sand, which are consumed in enormous quantities for numerous industrial purposes.

ILLUSTRATIONS.

Photomicrographs by reflected light.

Fig. 1. Crushed siliceous sandstone, Guiseley, Yorks., magnified 20 diam.
,, 2. Sand from Ottawa, Ill., U.S.A., magnified 16 diam.
,, 3. Sand from Leighton Buzzard, Beds., magnified 20 diam.
,, 4. Sand from Huttons Ambo, Yorks., before being washed, magnified 21 diam.
,, 5. Sand from Huttons Ambo, Yorks., after being washed, magnified 21 diam.
,, 6. Crushed vein quartz, Achil I., magnified 21 diam.
,, 7. Graphical expression of mechanical analyses of sands.

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